Integrated Crop Management of Hot Pepper (*Capsicum* spp.) in Tropical Lowlands

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Proefschrift

ter verkrijging van de graad van
doctor in de landbouw- en milieuwetenschappen
op gezag van de rector magnificus,
Dr. C.M. Karssen,
in het openbaar te verdedigen
op vrijdag 9 december 1994
des namiddags te vier uur in de Aula
van de Landbouwuniversiteit te Wageningen.

CIP-DATA KONINKLIJKE BIBLIOTHEEK, DEN HAAG

Vos, J.G.M.

Integrated crop management of hot pepper (*Capsicum* spp.) in tropical lowlands / J.G.M. Vos. - [S.l. : s.n.]. -
Ill., fig., tab.
Thesis Wageningen. - With ref. - With summary in Dutch.
ISBN 90-5485-317-4
Subject headings: integrated crop management / hot pepper production / tropical lowlands / crop health.

This book will be translated into Indonesian and made available to Indonesian research institutes, universities, extension services, policy agencies, and non-governmental organisations.

Cover: Harvest of hot pepper in Tegal, Central Java, Indonesia.
Printed by: Ponsen & Looijen, Wageningen, the Netherlands.

The study described in this thesis was performed at the Lembang Horticultural Research Institute (LEHRI), P.O. Box 1586, Bandung, Indonesia, at Wageningen Agricultural University (WAU), Department of Phytopathology, P.O. Box 8025, 6700 EE Wageningen, the Netherlands, and at the Malaysian Agricultural Research and Development Institute (MARDI), P.O. Box 186, 41720 Klang, Selangor Darul Ehsan, Malaysia.

Financial support was received from Directoraat Generaal Internationale Samenwerking (DGIS) of the Dutch Ministry of Foreign Affairs, from the Foundation "Johanna Westerdijkfonds" and from the Foundation "Fonds Landbouw Export Bureau 1916/1918".

Stellingen, behorende bij proefschrift

Integrated crop management of hot pepper (*Capsicum* spp.) in tropical lowlands

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Wageningen, 9 december 1994

1. Het misbruik dan wel overmatige gebruik van pesticiden door telers van hete peper (*Capsicum* spp.) in sommige belangrijke produktiegebieden in het laagland van Java in Indonesië is ontstaan als gevolg van eenzijdige voorlichting over of actieve promotie van pesticiden in die gebieden.
   Dit proefschrift.

2. De simultane aantasting van bepaalde gewas-stadia van hete peper door diverse ziekte- en/of plaag-organismen heeft tot gevolg dat onderzoek aan eenzijdige bestrijding van een individuele beschadiger in de praktijk niet wordt gewaardeerd.
   Dit proefschrift.

3. Het gebruik van mulch ter bestrijding van virus en trips in hete peper kan pas als volwaardig element van de geïntegreerde teeltwijze (GT) worden toegepast, indien milieu-vriendelijke materialen voor het mulchen beschikbaar komen.
   Dit proefschrift.

4. De introductie van hete-peperrassen met partiële resistentie tegen antraknose zal een belangrijke bijdrage leveren aan het succes van de geïntegreerde teeltwijze (GT) tijdens natte seizoenen.
   Dit proefschrift.

5. De stelling "The ideals of integrated pest management (IPM) cross discipline boundaries, yet its practice appears totally discipline dependent" van Barfield en Swisher (1994) ondersteunt de strekking van dit proefschrift.

   Barfield, C.S. and Swisher, M.E., 1994. Historical context and internationalization of IPM. Food Reviews International 10: 215-267.

6. Het zoeken naar methoden om tropische hooglandgewassen, zoals aardappel, in tropisch laagland te telen lijkt op het dresseren van een paard om op twee benen te lopen.

7. Het opschorten van ontwikkelingsgelden als politiek pressiemiddel getuigt van politieke hypocrisie, aangezien voornamelijk politiek machtelozen, met name kansarme doelgroepen, de dupe worden.

8. Het rendement van ontwikkelingsgelden kan worden verhoogd door te bezuinigen op buitenlandse missies en meer verantwoordelijkheden te delegeren naar de project-uitvoerenden ter plaatse.

9. De formulering van wetenschappelijke projectvoorstellen wordt in hoge mate beïnvloed door politieke en maatschappelijke trends en voorkeuren.

10. De duurste vrede is goedkoper dan de billijkste oorlog.
    Alexander Pola.

11. Dit proefschrift wordt niet zonder pronk verdedigd.

12. Some like it hot.
    Marilyn Monroe.

Ter herinnering aan mijn moeder

Author's abstract

Vos, J.G.M. (1994). Integrated crop management of hot pepper (*Capsicum* spp.) in tropical lowlands. PhD Thesis, Wageningen Agricultural University, the Netherlands, 188 pp., 64 tables, 34 figures, English and Dutch summary.

Hot pepper (*Capsicum* spp.) is the most important low elevation vegetable commodity in Indonesia. Yields are low, in part due to crop health problems. Farmers' practices were surveyed by means of exploratory surveys. Hot pepper pests and diseases were identified and described. Components of integrated crop management (ICM) of hot pepper were investigated, such as plant raising practices during the nursery phase, and mulching and nitrogen fertilizing during the field phase. Experiments were carried out in the field at various locations in Indonesia and Malaysia and in growth chambers and greenhouses in the Netherlands. During the nursery phase, screen-covered nurseries protected plants from aphids and aphid-transmitted viruses. In the field phase, after transplanting, potted transplants showed better crop establishment than bare-root transplants and earlier harvesting. When plantlets were raised in screen-covered nurseries, a plant raising period of 1½ months appeared best for plant growth and earliness of harvesting after transplanting. In the field phase, white and silvery plastic mulches improved plant growth and earliness of fruiting, reduced virus infection and thrips injury, and improved crop production. Nitrogen fertilizing improved plant growth. Increasing nitrogen application rates aggravated anthracnose fruit rot and *Cercospora* leaf spot. Best yields were attained with nitrogen fertilization of 150 kg N/ha. The investigated components of ICM benefitted crop production through, among others, improvement of crop health. The effects of the ICM components on yield were irrespective of cultivar or location.

Additional key words: Correspondence analysis, crop loss, crop phenology, cultural practices, feasibility studies, pest and disease assessments, production areas, production constraints, symptomatology.

Contents

Outline of this book

Hot pepper (*Capsicum* spp.) is a major vegetable in Southeast Asian countries. In Indonesia, it is the most important lowland vegetable, in terms of cultivated area and production value. Other countries in Asia, where hot pepper is extensively grown, are Malaysia, Thailand, India, Korea and China. Pests and diseases cause main production constraints. Problems with crop health cause extremely intensive use of pesticides in many vegetable production areas in Asia, leading to (i) soil and water pollution, (ii) high risks of intoxication to people handling the pesticides and the crop, (iii) probably large pesticide residues on marketable produce, and (iv) high production costs.

Little information was available on the production of hot pepper in the humid tropical lowlands. A brief outline of hot pepper production in Indonesia was given by Zeijlstra (1949) and some notes, mainly on taxonomical aspects, were produced by Ochse (1931). Literature searches showed that, since those early handbooks, publications concerning pesticide screening were numerous, but studies on alternative methods of crop protection were rare.

The concept of integrated crop management (ICM) (FAO, 1991) has been developed from the more commonly applied concept of integrated pest management (IPM) (FAO, 1973). Both IPM and ICM aim to minimize pesticide use, but whereas IPM tends to focus on the pests (including diseases) and their control, ICM tends to focus on the crop and to maintain its health (Chapter 1).

The concept of ICM is new. Aware of the negative side effects of pesticides, the Western world began a search for pest control practices with reduced chemical inputs, such as supervised control and biological control by means of natural enemies. The applicability of such pest control practices depends heavily on the knowledge of researchers, extension staff and farmers about the symptomatology and biology of harmful and beneficial organisms, and about decision making. Such prerequisites for successful application of supervised and/or biological control are often not available in developing countries.

To achieve ICM, farmers' crop management methodologies are studied and transformed into components of ICM. During the first phase of the research, that began in Indonesia in August, 1988, exploratory surveys in six major hot pepper production areas on Java were conducted to describe current crop management practices of small farmers (Chapter 2). An inventory of pests and diseases was made, identification studies performed and crop health observation methods defined (Chapter 3).

Based on the results of surveys, field visits and literature research, it was decided to pay major attention to plant raising (Chapter 4), mulching (Chapters 5 and 6) and nitrogen fertilizing (Chapter 7). Field trials were conducted to investigate effects of each of the three crop management techniques individually and in combinations, at different experimental sites and during different seasons. On-farm field experimentation was initiated. Fieldwork was done in Indonesia and Malaysia, greenhouse and growth chamber experiments in the Netherlands.

A chronological overview of experiments conducted at the different locations and countries, and references to relevant chapters of this book, is given in Table 1. In the general discussion (Chapter 8) a synoptic evaluation of all field trial results is given using descriptive statistical methods.

Table 1. Locations and time indications of hot pepper trials, that were realized to test various plant raising, mulching and nitrogen fertilizing aspects, and references to relevant chapters of this book.

Trial	Location	Country	Period	Factors	Chapter(s)
A.	Brebes	Indonesia	Aug'89-Jan'90	Nursery cover Seed bed	4, 8
B.	Brebes	Indonesia	Dec'89-Mar'90	Mulch Plant density	5, 6, 8
C.	Subang	Indonesia	Jun'90-Sep'90	Mulch	5, 6, 8
D.	Tegal	Indonesia	Jul'90-Nov'90	Mulch	5, 6, 8
E.	Subang	Indonesia	Aug'90-Jan'91	Nursery cover Seed bed	4, 8
F.	Subang	Indonesia	Feb'91-May'91	Mulch	5, 6, 8
G.	Subang	Indonesia	Feb'91-Jun'91	Nitrogen Fungicide	7, 8
H.	Subang	Indonesia	Mar'91-Jul'91	Nursery cover Seed bed Nursery period	4, 8
I.	Subang	Indonesia	Aug'91-Dec'91	Mulch Nitrogen	5 - 8
J.	Subang	Indonesia	Nov'91-Apr'92	Nursery cover Seed bed Nursery period	4, 8
K.	Subang	Indonesia	Jan'92-May'92	Mulch Nitrogen	5 - 8
L.	Wageningen	Netherlands	Jul'92-Dec'92	Nitrogen Cercospora	7
M.	Wageningen	Netherlands	Nov'92-Apr'93	Nitrogen Cercospora	7
N.	Klang	Malaysia	Apr'93-Nov'93	Plot size	8
O.	Klang	Malaysia	May'93-Dec'93	Nursery cover Nursery period	4, 8
P.	Klang	Malaysia	Aug'93-Dec'93	Mulch Nitrogen	5 - 8
Q.	Klang	Malaysia	Aug'93-Jan'94	Nursery cover Mulch Nitrogen	4 - 8
R.	Klang	Malaysia	Sep'93-Mar'94	Nursery cover Mulch	4 - 6, 8

Chapter 1

Hot pepper (*Capsicum* spp.) production on Java, Indonesia: toward integrated crop management

J.G.M. Vos and A.S. Duriat

Crop Protection. In press.

Abstract: In Indonesia, hot pepper (*Capsicum* spp.) is the most important low elevation vegetable commodity in terms of production area and value. The yield levels are low (2.8 t/ha in 1989). Poor crop health, low quality of seed material, high production costs, fluctuating market prices, and farmers' lack of knowledge are major production constraints. Integrated crop management (ICM) is proposed to overcome major problems with crop health. ICM focuses on crop health by optimizing crop conditions. ICM seems to be a suitable approach for vegetable production under tropical lowland conditions, and should lead to ecologically, toxicologically and socio-economically sound practices.

1.1 Introduction

Indonesia is an archipelago with a total land area of 1.9 million km². About 44 % of this land area is used for agriculture (including estate crops). Most of the Indonesian population (in 1990: 180 million) is concentrated on the island of Java, where 110 million people live on 7 % of Indonesia's land surface. The bulk of the vegetable production takes place on Java.

Java is located between 105° - 115° Longitude East and 5° - 8° Latitude South. The humid tropical climate is influenced by the West Monsoon, causing a rainy season from November until April, and the East Monsoon, causing a dry season from May until October. The average temperature at sea level is 27 °C. The annual precipitation varies between 1500 mm in the Eastern part and 4200 mm in the Western mountainous areas of Java (Oldeman, 1975).

Vegetables are produced at elevations ranging from sea level in coastal zones up to 1500 m above sea level in mountainous areas. Tropical vegetable crops, such as hot pepper, amaranth, cucumber, eggplant, kangkung, shallot and yardlong bean, dominate at low elevations. At high elevations temperate vegetables are produced, including potato, cabbage, carrot and garlic. Based on the area distribution of vegetable crops among elevations, Buurma and Basuki (1990) distinguished three zones of vegetable production: low elevations, below 200 m above sea level; medium elevations, 200 - 700 m above sea level; and high elevations, above 700 m above sea level. The medium elevation zone was separated into a 'lower' and 'higher' sub-zone by the 450 m line (Buurma, 1989).

Hot pepper is a typical low elevation crop, with the largest hectareage and the highest production value of all vegetables (Table 1.1). The total annual production of hot pepper in Indonesia increased from 208,000 t (103,000 ha) in 1980 to 479,000 t (172,000 ha) in 1989. In 1989, 61 % of the total harvested area of hot pepper was located on Java. Production of hot pepper in Indonesia meets local needs as the import and export of hot pepper are quite limited. Imports rose from 5 t in 1980 to 2,550 t in 1988, 98 % consisting of dry hot pepper. The export of hot pepper was nil in 1980, rose to a maximum of 306 t in 1983 and decreased again to 11 t in 1988. The average annual consumption of hot pepper in Indonesia is 2.4 kg per capita (Source: Central Bureau of

Table 1.1. Areas[1], yields[2] and production values[3] of major vegetable commodities in Java, Indonesia, in 1989.

Commodity	Scientific name	Planted area (%) below 200 m asl[4]	Planted area (%) below 450 m asl[4]	Harvested area ($\times 10^3$ ha)	Average yield (t/ha)	Production ($\times 10^3$ t)	Mean price (IDR/kg)	Prod. value (10^9 IDR)
Hot pepper	*Capsicum* spp.	69	79	94	3.3	309	580	179
Shallot	*Allium cepa*	71	77	39	7.4	290	560	162
Garlic	*Allium sativum*	3	7	12	6.3	76	1600	122
Potato	*Solanum tuberosum*	0	5	25	15.4	385	230	89
Cabbage	*Brassica oleracea*	2	6	35	18.4	643	120	77
Bunching onion	*Allium fistulosum*	4	17	21	9.8	206	190	39
Yardlong bean	*Vigna sesquipedalis*	69	87	56	3.5	194	200	39
Tomato	*Lycopersicon esculentum*	28	43	16	7.8	125	230	29
Cucumber	*Cucumis sativus*	72	86	27	7.0	188	130	24
Chinese cabbage	*Brassica chinensis*	16	23	18	9.9	179	130	23
Carrot	*Daucus carota*	0	3	11	14.7	162	130	21
Snap bean	*Phaseolus vulgaris*	8	25	16	6.1	97	200	19
Eggplant	*Solanum melongena*	70	85	16	6.6	105	130	14
Red bean	*Phaseolus vulgaris*	43	50	36	1.3	45	300	14
Kangkung	*Ipomoea aquatica*	79	91	8	11.0	88	90	8
Amaranth	*Amaranthus* spp.	72	88	14	3.7	52	130	7

[1]Source planted areas: Lembang Horticultural Research Institute vegetable databank, 1987.
[2]Source harvested areas and production: Central Bureau for Statistics, Jakarta, 1989. Average yield = 'Production in t'/'Harvested area in ha'.
[3]*Source mean prices: Farm-gate prices* collected by Directorate for Farm Economics Jakarta (average high elevation vegetable prices over 1985-1988) and Service of Agriculture West Java (average low elevation vegetable prices in 1988 (1 US\$ ≈ 2009 IDR)), West Java. Data represent mean prices in West Java only. Prod. value = Production value = 'Production in 10^3 t'*'Mean price in IDR/t'.
[4]Asl = Above sea level.

Statistics, Jakarta, 1981-1990).

This chapter describes the status of hot pepper production on Java, with special attention to production constraints. The causes of low production levels are analyzed and integrated crop management (ICM) is proposed as a direction to applied, problem solving research.

1.2 Hot pepper production

Capsicum *species and fruit types*

Several *Capsicum* species are grown on Java. Three major hot pepper types are distinguished by fruit shape. The local names of these hot pepper types are *cabe besar*, *cabe keriting* and *cabe rawit* (respectively: big pepper, curled pepper, small pepper). This fruit type classification is for convenience only, and bears no relation to taxonomic classifications. The major *Capsicum* species on Java are *C. annuum* L. and *C. frutescens* L.

Plants of *C. annuum* are annuals with dark green, ovate leaves and solitary flowers with white petals. The fruits are usually pendent (sometimes erect) and moderately to very pungent. The fruit shape is long and straight (Ind.: *cabe besar*; Figure 1.1) or slender and curling (Ind.: *cabe keriting*; Figure 1.2). The fruits are light to dark green when unripe and red when mature. Some *C. annuum* types produce erect or pendent small fruits (Ind.: *cabe rawit*).

Hot peppers of *C. frutescens* have a perennial growth habit. The foliage is light green and the leaves are ovate to elliptical. The flowers are borne in small clusters and have pale green petals. The fruits are small, straight, sometimes slightly corrugated, and usually borne erect (Figure 1.3). The fruit colour is pale green to yellow when unripe, dark orange to red when ripe and the pungency is generally high.

Confusion arises when small-fruited hot peppers show all characteristics of *C. frutescens*, but do not bear their flowers and fruits in clusters. According to Smith and Heiser (1951) the cluster characteristic is decisive for distinction between *C. annuum* and *C. frutescens*. Heiser and Pickersgill (1969) consider the small-fruited hot pepper type with single-fruited axils a 'spontaneous variety' of *C. annuum* and regard *C. annuum* var. *minimum* (Miller) Heiser as the earliest proper classification. In a later publication, Pickersgill (1989) posed as a rule of thumb that *C. annuum* has pure white corollas and *C. frutescens* greenish white corollas. The dominant hot pepper types in major production areas on Java have been classified accordingly.

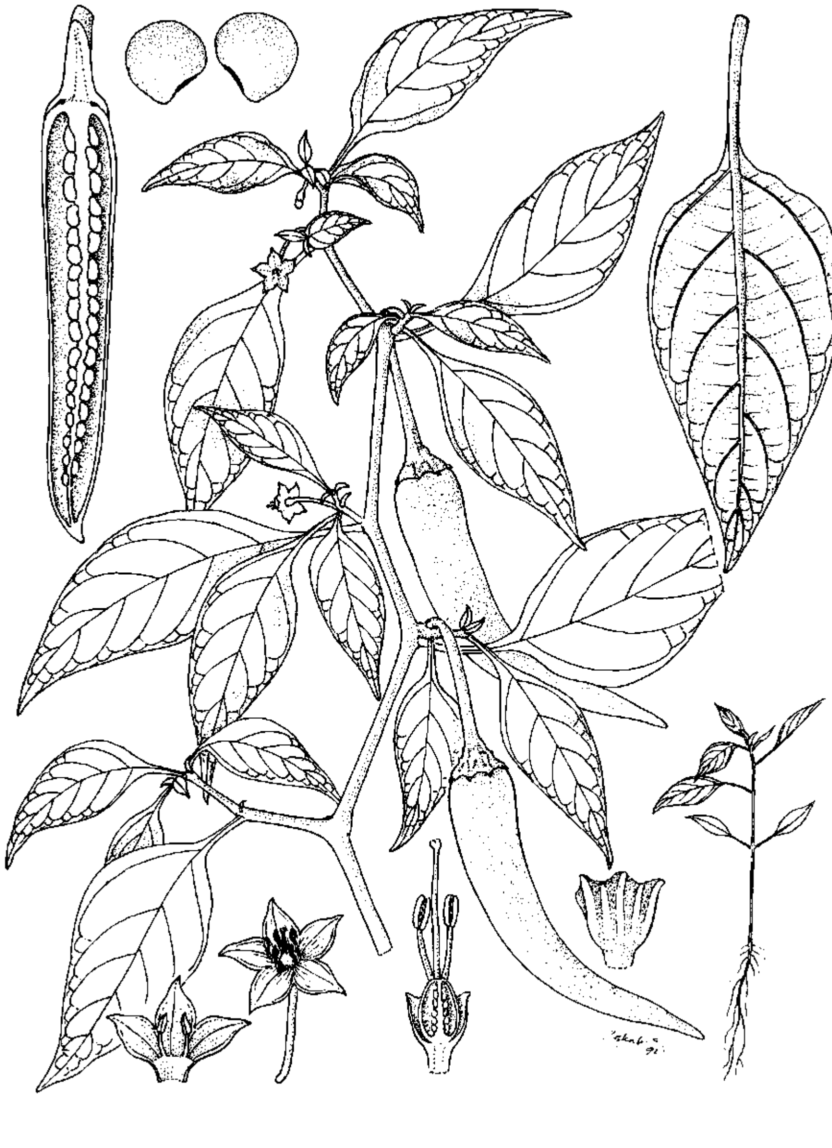

Figure 1.1. *Capsicum annuum*, grown on a large scale on Java, with the *cabe besar* fruit type (Eng.: big pepper). Original drawing by Mr. Iskak, Herbarium Bogoriensis, Indonesia.

Figure 1.2. *Capsicum annuum*, grown on a large scale on Java, with the *cabe keriting* fruit type (Eng.: curled pepper). Original drawing by Mr. Iskak, Herbarium Bogoriensis, Indonesia.

Figure 1.3. *Capsicum frutescens*, grown on a large scale on Java, with the *cabe rawit* fruit type (Eng.: small pepper). Original drawing by Mr. Iskak, Herbarium Bogoriensis, Indonesia.

Hot pepper production areas

Hot pepper production is scattered over Java. Using 1987 district[1] statistics, six areas of hot pepper production were discerned (areas I - VI in Figure 1.4). A low elevation hot pepper area was defined as a group of adjacent low elevation districts with each at least 100 ha, adding up to over 1000 ha of hot pepper. In 1987, about 60 % of the Javanese low elevation hot pepper was planted in such hot pepper areas. One of the areas (Area IV) covered over 15,000 ha, whereas the five other areas ranged from 1,100 to 3,100 ha. One *Capsicum* species, with a single fruit type, generally dominated hot pepper cultivation in each area (Table 1.2).

The six hot pepper areas on Java are characterized by different environmental conditions and cropping systems (Table 1.3). The areas are typified by an average elevation between 10 and 42 m above sea level and a clayish soil. An important factor, in addition to elevation and soil type, is the availability of irrigation water. In irrigated areas, hot pepper is mostly cultivated during the dry season. By law, these areas are often destined to be used for wetland (Ind.: *sawah*) rice production during the wet season. In rainfed areas, hot pepper production is restricted to the rainy season. When some kind of irrigation is available, these areas may be used for hot pepper production during the dry season.

Hot pepper yield capacity

A preliminary experiment comparing fruit yields of different cultivars was executed in 1990 in Subang (West Java; 110 m above sea level) at the Lembang Horticultural Research Institute (LEHRI). Indonesian landraces and an imported Taiwanese hybrid, 'Hot Beauty' (Known-You Seed), planted in polybags, were grown in a screenhouse of 6 m wide, 18 m long and 3 m high. Yields were greatly increased compared to unscreened field results.

As a follow-up, yield capacities of some popular local *C. annuum* selections were tested in Subang in 1991 at LEHRI. The level of attainable yield (Zadoks and Schein, 1979) under tropical lowland conditions was to be derived from the screenhouse in the Subang trial in 1991. The yield assessment trial was conducted in a split-plot design with three replications, two main plot treatments and five split plot treatments. The main plot treatments were: A1 screenhouse, i.e. a tunnel (2 m high, 3 m wide, 24 m long, covered with nets of 560 μm meshed screen), and A2 open field. The split plot treatments were different hot pepper cultivars: B1 'Jatilaba', B2 'Tit Paris', B3 'Tampar', B4 'Hot Beauty' and B5 'Long Chilli'. Daily average temperatures varied between 24.3 and 28.6 °C. The yields in the screened tunnels of the Indonesian landraces B1 - B3 ranged from 2.1 to

[1]A district (Ind.: *kecamatan*) is an administrative unit: Java is divided into provinces (Ind.: *propinsi*), subdivided into regencies (Ind.: *kabupaten*), each regency being divided into districts.

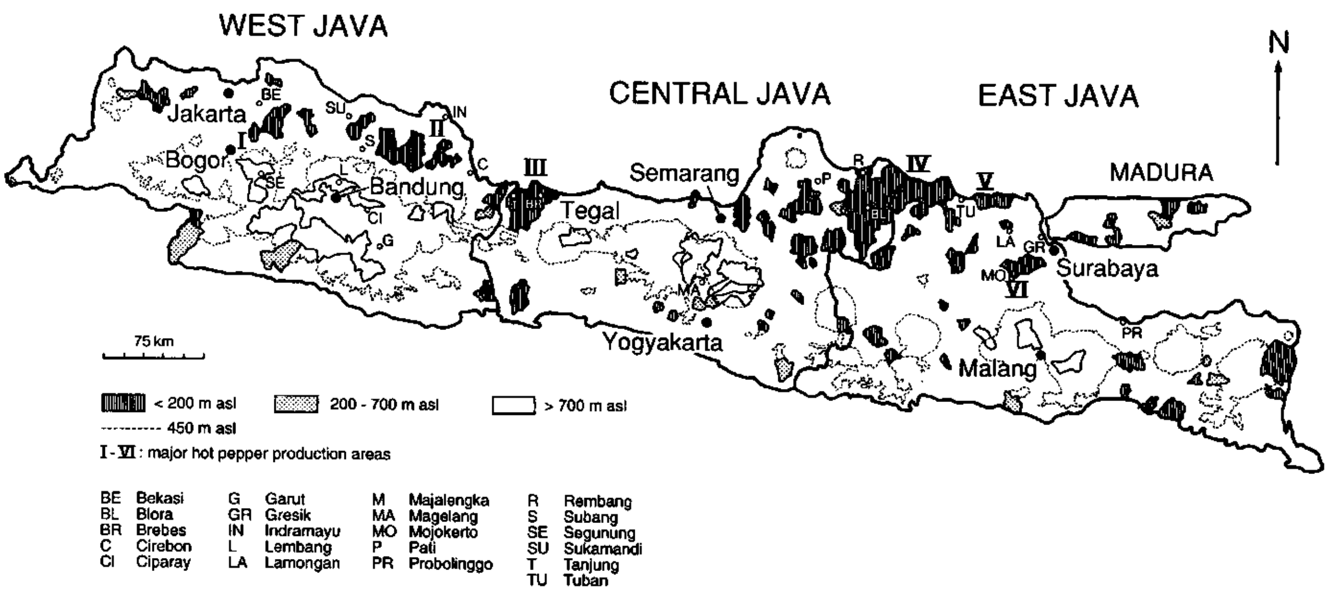

Figure 1.4. Hot pepper production at low, medium and high elevations on Java and Madura, 1987 (sources: Lembang Horticultural Research Institute vegetable databank 1987; Anonymous, 1971). Drawing by Mr. P.J. Kostense, Wageningen Agricultural University, the Netherlands.

Table 1.2. Locations, areas[1] and main *Capsicum* species of six low-elevation hot pepper production areas on Java, 1985-1987.

Area code	Province	Regencies	Mean hectareage of newly planted hot peppers (1985 - 1987)	Dominating *Capsicum* spp.	Dominating fruit type(s)
I	West Java	Bekasi, Bogor	2700	*C. annuum*	Big
II	West Java	Majalengka, Indramayu, Cirebon	1100	*C. annuum*	Big
III	Central Java	Brebes, Tegal	2800	*C. annuum*	Big
IV	Central Java East Java	Pati, Rembang, Blora Tuban	15100	*C. annuum* and *C. frutescens*	Big, curled and small
V	East Java	Lamongan	1200	*C. frutescens*	Small
VI	East Java	Gresik, Mojokerto, Surabaya	3100	*C. frutescens* and *C. annuum*	Small and big
Total area low elevation hot pepper in Java and Madura (1987)			45851		

[1]Source: Lembang Horticultural Research Institute vegetable databank 1985-1987.

Table 1.3. Physical conditions, use and planting periods[1] of six low-elevation hot pepper production areas on Java.

Area	Elevation (average m asl[2])	Main soiltype	Average clay %	Irrigation[3]	Mainly *sawah/tegal*[4]	Main planting month(s)	Main production season
I	36	Nitosol/Fluvisol	50%	1 - 4	*Sawah*	Aug	Dry season
II	12	Fluvisol	75%	3 - 4	*Sawah*	Oct - Dec	Wet season
III	15	Fluvisol	70%	3 - 4	*Sawah*	May - July	Dry season
IV	42	Vertisol	65%	1 - 3	*Tegal*	Oct-Dec & Mar-May	Wet & Dry season
V	10	Fluvisol	70%	1	*Tegal*	Dec - Feb	Wet season
VI	17	Vertisol	75%	1	*Tegal*	Nov - Jan	Wet season

[1]Sources: Lembang Horticultural Research Institute vegetable databank 1987; FAO/UNESCO soil map of the world 1976. No. 9.
[2]Asl = Above sea level.
[3]1 = Rainfed; no irrigation canals; 2 = Construction of irrigation canals partly financed, but not managed by the government; 3 = Irrigation canals constructed but not managed by the government; 4 = Irrigation canals completely constructed and managed by the government.
[4]*Sawah* = Field surrounded by bunds to contain water so that wetland rice can be grown; *Tegal* = Dryland used for seasonal crops.

9.0 t/ha. The Taiwanese cultivars 'Hot Beauty' and 'Long Chilli' yielded respectively 9.0 and 4.9 t/ha. The yields in the open field (A2: "actual yields") were below average and the yields in the screenhouse (A1: "attainable yields") below expected, possibly due to low soil pH and very early infection by unidentified virus(es).

An indication for the level of attainable yields under glasshouse conditions in the Netherlands was derived from a preliminary yield assessment trial at the Glasshouse Crops Research Station (GCRS) in Naaldwijk, the Netherlands, in 1992. In addition to three Indonesian landraces and one Taiwanese cultivar, three other hot pepper cultivars were included that are grown on a small scale under glasshouse conditions in the Netherlands. The trial was conducted in a randomized complete block design with two replications. Daily average temperatures ranged from 21 to 29 °C. Daylengths ranged from about 10 hrs at planting time to 17 hrs at harvest time. No supplementary light was given. In this trial the exotic material from Indonesia and Taiwan showed late flowering and production compared to the Dutch cultivars.

The results of the three described trials were analyzed as single factor experiments by analyses of variance. Treatment means were separated by Tukey's significant difference test in case of significant treatment effects (Table 1.4). Yields of Dutch standard export quality fruits ranged from 3.7 to 16.9 t/ha for the Indonesian landraces, compared to 23.5 to 42.8 t/ha for the Dutch cultivars. Production levels of the Indonesian landraces might be improved by selection for earliness. Substantial variation in yield levels appeared between the three trials. The yields of the Indonesian cultivars with big fruit types were not inferior to the Taiwanese cultivars. Under glasshouse conditions in the Netherlands, the Dutch cultivars excelled the Indonesian and Taiwanese cultivars. The average actual yield of hot pepper on Java is 3.3 t/ha. However, yields of up to 29 t/ha were recorded in farmers' fields in Brebes (Area III in Figure 1.4). Such differences in yield, the 'yield gap', demonstrate the relevance of production constraints.

1.3 Constraints of hot pepper production

The major constraints of hot pepper production were listed during a workshop, aimed at planning farmer-oriented, on-station and on-farm, research (on farm client oriented research (OFCOR) method: Tripp and Woolley, 1989), held at LEHRI in 1991 and attended by researchers, extension workers and policy makers. Five categories of major constraints were distinguished: (1) poor crop health, (2) low quality of seed material, (3) high production costs, (4) marketing problems, and (5) farmers' lack of production knowledge (Duriat *et al.*, 1991).

Crop health

The magnitude of the constraint posed by pests and diseases is illustrated by LEHRI

Table 1.4. Yields[1] of Indonesian, Taiwanese and Dutch cultivars of hot pepper in yield assessment trials in Subang (West Java; 110 m above sea level) under screen tunnel conditions, and in Naaldwijk (The Netherlands) under glasshouse conditions.

Cultivar	Origin		Fruit type	Subang 1990	Subang 1991	The Netherlands 1992
Flamy	The Netherlands	(De Ruiter Seed)	Big	-	-	23.5 b
Furila	The Netherlands	(De Ruiter Seed)	Big	-	-	42.8 a
Hot Beauty	Taiwan	(Known-You Seed)	Big	18.0	9.0 a	17.1 c
Ir	Indonesia		Big	12.8	-	-
Jatilaba	Indonesia		Big	16.5	6.0 ab	11.0 c
Long Chilli	Taiwan	(Known-You Seed)	Big	-	4.9 ab	-
Semarangan	Indonesia		Big	16.9	-	-
Tampar	Indonesia		Curled	-	2.1 b	3.7 d
Tit Paris	Indonesia		Big	16.2	9.0 a	16.9 c
Torito	The Netherlands	(De Ruiter Seed)	Big	-	-	24.1 b
					$TSD_{0.05}$=1.3	$TSD_{0.05}$=1.1

[1]Yields are expressed in tonnes fresh, healthy fruits per hectare.

experiments. According to Kusandriani (unpublished LEHRI data) an untreated block in a 1990 germplasm trial in Subang yielded only 28 % of the average yield obtained in regularly with pesticides sprayed blocks. Other LEHRI assessments on crop losses due to major hot pepper pests and diseases on Java are summarized in Table 1.5. The estimated yield losses due to one or more pests and diseases range from 12 to 66 % (Table 1.5).

Major hot pepper pests are thrips (*Thrips parvispinus* Karny) and yellow tea mite (*Polyphagotarsonemus latus* Banks). Thrips particularly causes problems during prolonged dry periods. Other important pests are tropical armyworm (*Spodoptera litura* Fabricius), oriental fruit fly (*Bactrocera dorsalis* Hendel), cotton bollworm (*Heliothis armigera* Hübner) and a jassid (probably *Empoasca* spp.). Armyworms and bollworms may appear together and cause extreme damage. The widely distributed fruit fly is especially damaging in fruit production regions. Jassids are widespread, but yield losses have not been determined. Aphids (*Myzus* and *Aphis* spp.) are important virus vectors.

Major diseases are anthracnose fruit rot, caused by *Colletotrichum* spp., and virus diseases. Anthracnose can be severe during rainy periods. Virus symptoms are commonly found and are caused by one or more of the following, serologically identified viruses: cucumber mosaic virus (CMV), potato virus Y (PVY) and tobacco etch virus (TEV) (Duriat, 1989). Other diseases are *Cercospora* leaf spot (*Cercospora capsici* Heald & Wolf), bacterial wilt (*Pseudomonas solanacearum* (Smith) Smith) and southern blight (*Sclerotium rolfsii* Saccardo). *Cercospora* leaf spot is widely distributed and generally occurring, while bacterial wilt and southern blight are less regularly observed.

Parasitic nematodes are frequently found in dryland (Ind.: *tegal*) hot pepper production fields. The species encountered belong to the genera *Helicotylenchus*, *Rotylenchulus* and *Meloidogyne*. Nematode problems are considered to be of minor importance in wetland (Ind.: *sawah*) fields, where vegetables are rotated with wetland rice (Marwoto, unpublished LEHRI report).

Quality of seed material

Most hot pepper farmers grow local selections or landraces. The seed is produced on-farm or bought from local shops. Commercial cultivars are not commonly used. Only recently a Taiwanese hybrid cultivar ('Hot Beauty') has become popular in the districts of Magelang (Central Java) and Garut (West Java) (Anonymous, 1990a). In 1992 there were two local seed companies (East-West Seed Indonesia and Benih Prima) that produced seed of two hot pepper 'cultivars', which were in fact selections from the Brebes (Area III) landraces 'Jatilaba' and 'Tit Super'.

Locally produced seed has a variable quality without guarantee. Neither seed cleaning nor grading is applied and the germination capacity is not tested. Seed-borne diseases (such as anthracnose, viruses) may be present. Farmers' selection criteria for seed production vary from plants with high yields to fruits with specific size and shape. Seed

Table 1.5. Estimations of hot pepper yield losses due to important pests and diseases derived from LEHRI experiments in which best attained yields were compared with control or actual yields.

Major causal agent(s)	Type of experiment	Location[1]	Year	Season	Yield per unit		Loss (%)	Source[2]
					Best case	Worst case		
Pests:								
Fruit fly	Insecticide	Probolinggo f.	1975-76	Wet	8,130 g	3,910 g	52	1
Fruitfly+armyworm+thrips+aphids	Insecticide	Cirebon f.	1983	Dry	10,445 g	3,637 g	65	2
Fruit fly	Mulch	Brebes f.	1990	Wet	506 fruits	447 fruits	12	10
Fruit fly	Mulch	Subang f.	1990	Dry	337 fruits	293 fruits	13	10
Fruit fly	Plant raising	Subang f.	1990	Dry	337 fruits	280 fruits	17	10
Mites+aphids+thrips	Insecticide	Ciparay f.	1986	Dry	213 g	93 g	56	3
Mites+fruit fly+armyworm	Insecticide	Tanjung f.	1988	Dry	11,800 g	4,300 g	64	4
Thrips+mites	Insecticide	Tanjung f.	1989	Dry	3,980 g	3,160 g	21	10
Thrips+aphids	Bionomics	Brebes f.	1990	Dry	-	-	23	5
Diseases:								
Anthracnose+bacterial leaf spot	Fungicide	Brebes f.	1989	Wet	2,970 g	1,014 g	66	6
Anthracnose	Fertilizer	Subang f.	1990	Wet	348 fruits	282 fruits	19	10
Anthracnose	Fertilizer	Subang f.	1991	Wet-dry	1,711 fruits	1,345 fruits	21	10
Anthracnose	Mulch&fertilizer	Subang f.	1991-92	Wet	506 fruits	182 fruits	63	10
Cucumber mosaic virus	Cultivar	Segunung g.	1982-83	-	156 g	79 g	49	7
Chili veinal mottle virus	Inoculation	Segunung g.	1990	-	865 g	636 g	27	8
Potato virus Y	Inoculation	Segunung g.	1990	-	865 g	501 g	42	8
Rootknot nematodes	Mixed cropping	Segunung f.	1985	Dry	91 g	44 g	52	9
Tobacco mosaic virus	Inoculation	Subang g.	1990	-	286 g	207 g	28	10

[1]f.= field; g.= greenhouse.

[2]Sources: 1. Wiyoto and Nurhadi, 1979; 2. Soeriaatmadja, 1988; 3. Dibyantoro, 1988; 4. Sastrosiswojo *et al.*, 1990; 5. Setiawati, unpublished LEHRI report, 1990; 6. Suhardi and Suryaningsih, 1990; 7. Sulyo, unpublished LEHRI report, 1984; 8. Duriat, 1991; 9. Marwoto and Rohana, 1988; 10. Vos, unpublished data, 1989-1992.

lots, bought in local shops or markets, often consist of blends of local landraces. The genetic heterogeneity of the cultivated landraces contributes to a variable product quality.

Production costs and marketing

Considerable differences in input costs exist between hot pepper areas. When farmers run out of money, their crops are neglected or, instead, sold through pre-harvest transactions in exchange for down-payments or needed production inputs, such as pesticides. Due to the seasonality of the hot pepper production in each area (Table 1.3: 'main planting month(s)') local market prices fluctuate strongly as prices drop during harvest peaks. Price fluctuations are enormous, as much as fifteen fold in 1987/88 (Koster, 1989). As farmers cannot store perishable products, they are not able to wait and sell their products at a favourable price.

A survey of two wholesale markets in Jakarta indicated that four grade categories can be distinguished: I = 'Hot Beauty' (hybrid cultivar imported from Taiwan); II = produce from Brebes (Central Java); III = produce from Ujung Pandang (Sulawesi); IV = others. Apparently, grading is mainly related to the origin of the produce. Both wholesale markets mainly trade big fruit types. Only 20% of the pepper consumption in Jakarta is covered by small or curled types (Sofiari, unpublished LEHRI report). Assembly traders market hot peppers to wholesale markets in provincial capitals.

On the hot pepper assembly market at Tanjung (Area III), the following classes of big and curled fruit types (*cabe besar* and *cabe keriting*) are applied: I = long, thick fruit types ('Paris' and 'Tit'); II = shorter than I, thin and/or curling types ('Perembun' and 'Keriting'); III = green fruits; IV = diseased fruits. The price differences between classes I and II are relatively small. For example in November, 1991, class I valued IDR 1,500 (1 US$ ≈ 1,970 IDR) and class II IDR 1,300 per kg, while class III was priced at IDR 700 and class IV at IDR 200 per kg. When prices are sufficiently high, diseased fruits (class IV) are dried by assembly traders to be marketed as local dry pepper. This drying of hot peppers generally results in poor quality produce, not competitive with imported dry pepper. When prices are low, diseased fruits are discarded.

Farmers' production knowledge

The level of farmer knowledge as to hot pepper crop management is illustrated by the following information on the use of pesticides and fertilizers.

Farmers lack information concerning the symptomatology of hot pepper pests and diseases. Symptoms are often difficult to distinguish, because different causal agents, such as viruses, thrips and aphids, may give similar symptoms. Farmers usually refer to these particular symptoms with the general term *penyakit keriting daun* (Eng.: leaf curl disease). Pesticides are not applied according to target pests or diseases. Instead, the advice cf neighbouring farmers or pesticide shops is followed. Farmers often use the Indonesian term *obat* (Eng.: medicine) for pesticides, implying that these are curative substances. Pesticide inputs are sometimes very high: a cost-benefit analysis of hot pepper cultivation in Brebes (Area III) showed that 51 % of the input costs (including labour) were spent on pesticides alone (Basuki, 1988). In the area concerned, farmers complain that pesticides in use for many years have lost their effectiveness. This provokes farmers to increase the frequency of applications and in some areas 'pesticide cocktails' consisting of up to nine compounds are applied.

Fertilizer use is highly variable among and within hot pepper production areas. Recommendations for fertilization were being developed at LEHRI but these had not yet reached the farmers. Applications are unbalanced, with sometimes extremely high application rates of nitrogen (over 500 kg N per ha) and zero or low dosages of potassium and/or phosphorus. Foliar fertilizers are popular. Farmers often use the term *obat* (Eng.: medicine) for these chemicals too. Obviously, farmers need more basic information on plant nutrition.

1.4 Discussion and conclusions

In spite of its low yield, hot pepper is an important crop in terms of production volume and value. When the national production level (2.8 t/ha in 1989) of Indonesia is compared with that of other countries, Indonesia is far behind its Asian neighbour Malaysia with an average of 12 t/ha (Shukor *et al.*, 1989). In Thailand and India, however, average yields are 2 and 1 t/ha, respectively (Nikornpun and Lumyong, 1989; Singh and Cheema, 1989). Half a century ago, the total hot pepper area in Java was about 79,000 ha, with an average yield of 1.4 t/ha (Zeijlstra, 1949). The average yield increased to the present 3.3 t/ha. A further expansion of production is urgently needed. By the year 2000, the hot pepper production should increase to 1.5 times the 1989 level to meet the expected demand of the Indonesian population by that time (Van Lieshout, 1992).

The low production level is not the only matter of concern regarding hot pepper production in Indonesia. The negative impacts of reliance on pesticides for maintenance of crop health and high dosages of nitrogen are manyfold. During 1979-1986, 2,705 cases of poisoning with 236 deaths due to contamination of food products or to faulty application methods were recorded (Mustamin, 1988). In just harvested hot pepper fruits, residues were detected of monocrotophos (0.2 - 7.5 ppm) and chlorpyrifos (1.4 ppm) (Asandhi, 1989).

Reduced effectiveness of pesticides, mentioned by farmers, may be caused by pest resistance and/or due to counterfeit pesticides. Pest resistance has not yet been investigated in hot pepper. Falsified pesticides were detected during surveys of the Indonesian Department of Agriculture in 1987-1989 (Tjahjadi, 1989). According to Oka

(1988), adulteration of pesticides, cross-labelling, rebottling and repackaging frequently occur. Hot pepper pest resurgence has not yet been studied. The observation of uncontrollable thrips epidemics, only in hot pepper areas where pesticide use is extremely intensive (Vos *et al.*, 1991), possibly indicates resurgence. Environmental pollution due to excessive use of pesticides and fertilizers will eventually be recognized, when concerns arise over health-hazardous pesticide residues in vegetables and fish, nitrate contaminated ground and surface water, and reduction of ecological diversity. The reduction of the intensive use of pesticides and of nitrogen must be included as an important issue within the future crop management approach for hot pepper in Indonesia.

A major reason for failure of control programmes in developing countries is the 'tendency of excessively concentrating on insect pest problems alone, rather than on a broader spectrum of crop parasites and at the same time overlooking major agronomic, economic or social constraints' (Zelazny *et al.*, 1985). Climatic, edaphic and cultural factors are assumed to affect physiological processes in plants, leading to changes in the level of resistance and/or to shifts in nutritional suitability of the host (Tingey and Steffens, 1991). Discipline-oriented research, designed to control just one pest or disease, should therefore shift to crop and ecology-oriented investigations. The overall condition of the crop should become the major issue rather than the control of a single pest or disease. This approach is incorporated in the concept on integrated crop management (ICM).

In 1985, El-Zik and Frisbie (1985) defined ICM as 'a system whereby all interacting crop production and pest control tactics aimed at maintaining and protecting plant health are harmonized in the appropriate sequence to achieve optimum crop yield and quality and maximum net profit, in addition to stability in the agro-ecosystem, benefiting society and mankind'. They illustrated their theory with a cotton ICM model in the USA. In our view, the approach to maintain crop health throughout the crop's growth period, is the true ICM ideology. Heitefuß (1987) used the German term *Integrierter Landbau*. The term was translated as ICM and defined as 'a system of plant production most appropriate to the respective location and environment, in which, in consideration of economic and ecological requirements, all suitable procedures of agronomy, plant nutrition and plant protection are employed as harmoniously as possible with each other, utilizing biological-technological progress as well as natural regulatory factors of noxious organisms in order to guarantee long-term assured yields and economic success' (Heitefuß, 1989). In 1991, ICM was re-defined: 'ICM embraces all activities in the production system and is composed of several management activities focusing on particular constraints, such as integrated pest management, integrated nutrient management, integrated water management, and so on' (FAO, 1991). This definition illustrates the holistic approach of ICM in its broadest sense. As a working definition of ICM, that of El-Zik and Frisbie (1985) is preferred.

In the case of hot pepper, a further analysis of the five major production constraints described above shows that these are interrelated and linked to various production practices (Figure 1.5). The key problem is crop health. Crop protection technology components affect crop growth and development, harmful agents, their antagonists and the many interactions between crop, harmful agents and beneficials. Introduction of improved cultivars and the establishment of a seed certification scheme should lessen crop health problems.

Cultural techniques can alter the crop environment, improve plant vigour and resistance, and reduce survival and virulence of harmful agents. Examples are the modification of plant raising practices (use of screen covered cages will exclude sucking insects and infection with aphid-transmitted viruses during the nursery phase), the use of mulch (to reduce soil evaporation and leaching of nutrients; light-reflective mulch to alleviate virus problems) and the application of balanced fertilization (to improve growth, development and resistance level of the crop). However, Figure 1.5 shows that problems cannot be completely solved as long as farmers are deprived of basic information on crop nutrition, pest and disease symptomatology, natural enemies, biological and chemical pesticides, application techniques, and so on. In addition, the uncertainty of returns due to the fluctuating price of the product, may deter farmers from investing in ICM components that require initial inputs, such as modified nurseries or the application of mulch.

The following components of ICM research are elementary: (1) Survey of farmers' crop management practices; (2) Survey and identification of pests and diseases; (3) Experimental research on nursery practices; (4) Experimental research on mulching; (5) Experimental research on balanced fertilizing. Selection and breeding for resistance to major pests and diseases should be conducted continuously, simultaneous with the ICM research elements 1. - 5. Other components of ICM, such as biological control and habitat management, need a long-term research strategy. After on-station development of ICM components, on-farm testing should be performed in close collaboration with the extension service, following the OFCOR procedure.

On Java, the impact of hot pepper ICM will be the reduction of excessive use of agro-chemicals and the increased attention for cultural practices to improve hot pepper crop health. ICM should not induce pest resistance, pest resurgence or environmental pollution.

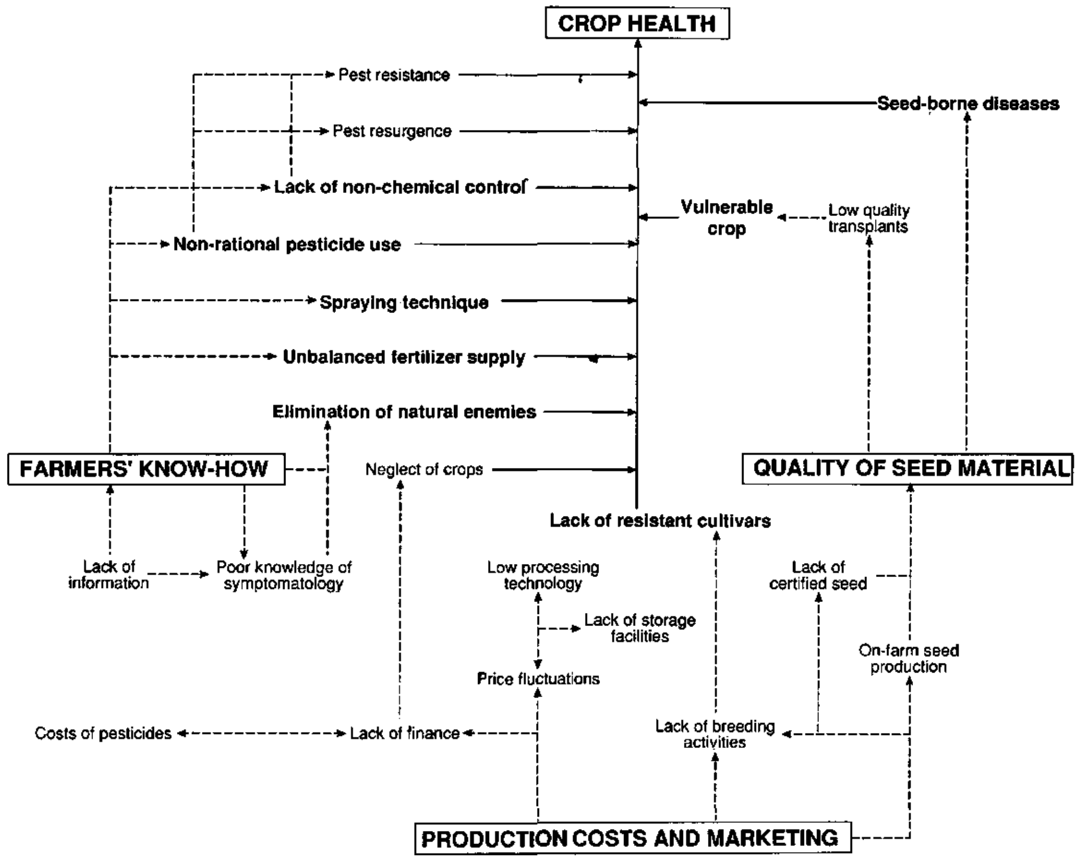

Figure 1.5. Technical constraints (capital, bold) and connected matters in hot pepper production on Java, including components that could be improved/modified by ICM (bold). Drawn lines represent direct relations with crop health, dashed lines indirect relations.

Chapter 2

An exploratory survey on farmers' practices and management of hot pepper (*Capsicum* spp.) on Java, Indonesia

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Journal of Plant Protection in the Tropics. In press.

Abstract: A field survey of management practices of hot pepper (*Capsicum* spp.) by farmers in six major production areas on Java, Indonesia, was conducted to study the problems of crop health. In general, farmers produce their own hot pepper seed, with little selection for yield, quality and seed health, apply unbalanced fertilization with often high dosages of nitrogen, and use variable (low to extremely high) quantities of pesticides. Yields were low (1 to 3 t/ha), except in the regencies of Brebes and Tegal (Central Java) where average yields were 12½ t/ha. Problems of crop health were mainly caused by caterpillars, fruit flies, mites, sucking insects, fruit rots, leaf spots, viruses and wilts. In order to overcome crop health problems, integrated crop management (ICM) components were selected from the disease tetrahedron. In this framework, improved nursery practices, use of resistant cultivars, mulching, balanced fertilization, optimized plant density, mechanical control, sanitation, use of insect traps, multiple cropping and crop rotation were promoted.

2.1 Introduction

Poor crop health is considered a major constraint in hot pepper (*Capsicum* spp.) production in Indonesia. Cultivars that are resistant to major pests and diseases are not available and chemical crop protection is not satisfactory. Therefore it was suggested that the problem be solved by means of integrated crop management (ICM) (Chapter 1). Within ICM, improvement of existing cultural practices is an approach to overcome farmers' problems with poor crop health.

Cultural practices applied by hot pepper farmers in Indonesia have hardly been investigated. Some notes, mainly on botanical aspects, were produced by Ochse (1931), and a brief outline of hot pepper production was given by Zeijlstra (1949). Descriptions of recommended crop management practices are given in at least three more recently published hot pepper crop manuals in the Indonesian language (Setiadi, 1987; Soewito, 1988; Sunaryono, 1989). Unfortunately, they describe sophisticated practices, which are not applicable to small-holder farmers. Besides these publications, some leaflets with concise information on hot pepper production have been produced by local extension services.

In order to investigate associations between farmers' crop management and the problems of crop health, exploratory surveys were conducted in six major production areas in Java (Chapter 1). An exploratory survey is "a process by which researchers traverse target regions and informally interview farmers and other persons knowledgeable of agriculture in order to arrive at a tentative understanding of farmers' existing technology for the target crop and to identify constraints limiting farmers' production and income" (Byerlee and Collinson, 1980). In each area, interviews and field visits were performed to collect data concerning farmers' crop management practices and to identify crop health problems.

In this chapter the results of exploratory surveys are discussed with emphasis on those crop management practices that could be modified into ICM components.

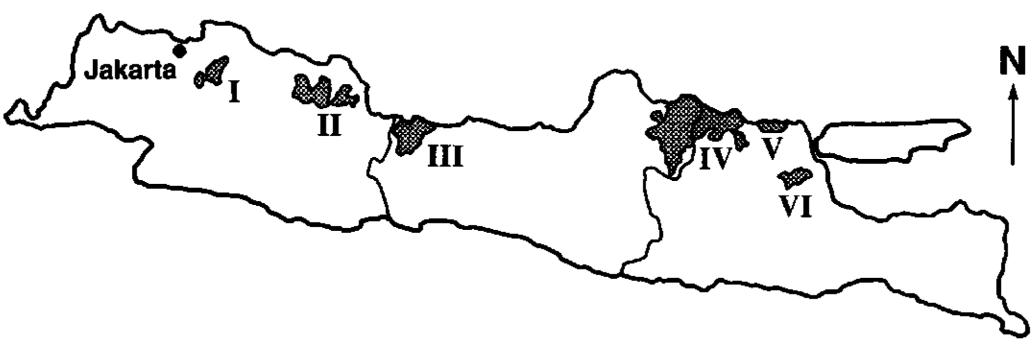

Figure 2.1. Major hot pepper production areas (I-VI) at low elevations on Java, Indonesia. Drawing by Mr. P.J. Kostense, Wageningen Agricultural University, the Netherlands.

2.2 Methodology

Six major hot pepper production areas (Area I - VI in Figure 2.1) were visited during appropriate growing seasons (Table 2.1). In each area, the regional[1] Service of Agriculture (Ind.: *Dinas Pertanian Tanaman Pangan*) and Field Extension Officers (Ind.: *Penyuluh Pertanian Lapangan*) assisted to select villages with high numbers of hot pepper growers and to organize individual or group discussions. The Service of Agriculture or Field Extension Officers occasionally helped to translate local languages into Indonesian. In total, 34 individuals and 18 groups of hot pepper farmers were interviewed. The groups consisted of, on average, six farmers. Questions concerned cropping systems, seed material, nursery practices, fertilizer use, pesticide use, yield, and problems encountered, especially crop

[1]A regency (Ind.: *kabupaten*) is an administrative unit: Java is divided into provinces (Ind.: *propinsi*), subdivided into regencies, each regency being divided into districts (Ind.: *kecamatan*).

health problems. In order to clarify the farmers' local nomenclature for pests and diseases, hot pepper fields were visited after each interview. The pests and diseases encountered were recorded, samples were taken for identification, and injury by pests and diseases was estimated. Impressions were recorded on the effects of the applied crop management in the field. In Area III, data were partly derived from a simultaneous Lembang Horticultural Research Institute (LEHRI) case study involving fertilizer and pesticide use. For additional information, farmers covered by this case study were interviewed.

2.3 Results

Crop management practices and farmers' problems varied according to production area. The results of the exploratory surveys on the crop management and on crop health are presented in this chapter.

Seasonality and cropping system (Table 2.1)

Hot pepper is produced during both dry (May - October) and rainy (November - April) seasons. Of the hot pepper hectareage in Java, about 50 % is planted during the dry and 50 % during the rainy season (Source: LEHRI vegetable databank, 1987). Dry season production generally takes place on wetland (Ind.: *sawah*) and rainy season production on dryland (Ind.: *tegal*). In dryland areas hot pepper can only be grown during the dry season when irrigation canals, rivers or wells are nearby.

Capsicum *species and hot pepper fruit types.* There are no data available on hectareages of the three prevailing hot pepper fruit types (big, curled and small hot pepper). Generally speaking, the big and curled fruit types are produced by *Capsicum annuum* L. and the small fruit type by *C. frutescens* L., although occasionally small fruiting *C. annuum* varieties are found (Chapter 1). Big fruits are mainly produced in the hot pepper areas in West and Central Java, while the mass production of small fruits appears to be located in East Java. The curled type is mainly produced in Rembang/Tuban (Area IV). Farmers' reasons for this distribution of hot pepper types are 'tradition', 'suitability of soil and climate' and 'marketability of the produce'.

Cropping system. Cropping systems vary from predominantly mono-crop cultivation in Bekasi (Area I) to different styles of mixed crop cultivation in the other areas. The crop rotation is determined by the hot pepper production season. Dry season production usually fits in a rotation with wetland rice during the wet season, namely rice-rice-hot pepper (→ soil about 8 months under water), or rice-hot pepper/other vegetable-hot pepper/other vegetable (→ soil about 3½ months under water). Wet season production generally takes place in dryland areas and rotates hot pepper with secondary food crops (Ind.: *palawija*) such as

Table 2.1. General information on major hot pepper production areas in Java, Indonesia, defined as target areas for exploratory surveys.

Area	I	II	III	IV	V	VI
Province of Java	West	West	Central	Central and East	East	East
Major regency(ies)	Bekasi	Cirebon	Brebes	Rembang and Tuban	Lamongan	Gresik
Hectareage in 1987*	2,700	1,400	3,000	13,900	1,400	3,200
# Farmers interviewed	4 Groups+1 Individual	3 Groups	26 Individuals	4 Groups+6 Individuals	2 Groups	5 Groups
Survey season(s)	Dry	Wet	Dry	Wet and dry	Wet	Wet
Survey period(s)	Oct 1990	Feb 1991	Jul 1991	Jan 1992 + Jul 1990	Mar 1991	Mar 1991
Dryland/Wetland	Wetland	Dryland	Wetland	Dryland	Dryland	Dryland
Major production season(s)*	Dry	Wet	Dry	Wet/Dry	Wet	Wet
Cropping system	Mono	Multiple	Relay	Multiple, mono	Multiple	Multiple,mono
Crop duration (month)	5	4½	4½	6½	7½	7
Main *Capsicum* species	*annuum*	*annuum*	*annuum*	*annuum+frutescens*	*frutescens*	*frutescens+annuum*
Prevailing fruit type(s)	Big	Big	Big	Curled + small + big	Small	Small + big
Field size (m^2)	400-10,000	700-7,000	700-8,100	1,000-10,000/200-5,000	2,000-10,000	500-10,000
Average plant distance (cm^2)	20x50	25x35	20x25	40x55	40x50	40x45
Raised beds system	No	No	Yes	No	No	No
Farmers irrigating (%)	70	65	100	45/100	0	0
Average yield (t/ha)	2.3	3.5	12.5	1.7/2.1	1.9	2.3

*Source: Lembang Horticulutural Research Institute vegetable databank, 1987.

peanut, soybean, cassava, maize: hot pepper-*palawija*-fallow. In the dryland rotation, soil is never inundated as in the wetland rotation. During the dry fallow period, there is no tillage or weed control. Problems with pathogenic soil organisms are therefore expected in dryland hot pepper production rather than in wetland production.

Harvesting and yield. The harvesting interval ranged between two and ten days. The average yield in Area III (12.5 t/ha) stands in sharp contrast to that of the other areas (1.7 to 3.5 t/ha). Yields of up to 29 t/ha were recorded in Area III. This probably explains why Area III is generally referred to as 'the most important hot pepper production area', whereas its hectareage is comparable to Area I and VI and only less than one fourth of Area IV.

Seed production, nursery practice and transplanting

Source of seeds (Table 2.2). Hot pepper seeds are mostly produced by farmers themselves. Generally, farmers select hot pepper plants for seed production in the field during harvest. Important selection criteria are fruit quantity per plant and fruit shape. Farmers who do not produce seeds buy processed seeds from fellow farmers or from traders at the local market. Some farmers buy seedlings, ready for transplanting, from fellow farmers. In Areas V and VI, farmers with a good supply of irrigation water during the nursery period sow large quantities of seeds and sell the surplus seedlings to other farmers in the area. In Area III, special plant raisers sell one month old seedlings. In one case (Area III) the seeds were purchased from food stalls, being waste of sambal preparations.

Nursery practice (Table 2.2). The growing of seedlings is similar in all areas, with the exception of Area III. Stable manure, fertilizers and sometimes a granular insecticide (carbofuran) are applied to a seedbed situated close to a source of water. Seed is broadcast sown, covered with fine soil and regularly irrigated. In Area II and IV, a roof of palm leaves or other plant material is often constructed to 'protect seedlings against sunshine and/or heavy rain'. In Area III, the general practice is the sowing of seeds (several seeds per hole) in the field between just-planted shallot bulbs.

Transplanting practice. The nursery period takes one to almost three months. When hot pepper is grown in the wet season, farmers start transplanting after the first rains. The irregular start of the rainy season incites farmers to prepare for an early planting date. Late rains delay planting and cause extended raising periods.

At planting, the plantlets are pulled out of the seedbed and transferred as bare-root seedlings. Some farmers rinse the roots with water prior to transplanting. In one village in Area VI, farmers trim the long roots of old seedlings to 5 cm to facilitate planting. This practice was described already in 1949 (Zeijlstra, 1949). Obviously, plants of six weeks and older, transplanted after trimming of the roots, experience a tremendous transplanting shock in the field and may be sensitive to soil-borne diseases. In Area III hot pepper is sown as

Table 2.2. Sources of seed material and nursery practices in six major hot pepper production areas on Java, Indonesia.

Area	I	II	III	IV (Wet)	IV (Dry)	V	VI
Seed material:							
Source of seed	Farmer	Farmer	Farmer/Others	Farmer	Farmer	Farmer/Others	Farmer/Others
Predominant landraces	Super	Lombok besar Super	Tit Paris Jatilaba Ir Perembun	Tampar Nos Keriting	Tampar Cangar Mentek	Jempling	Jemprit
Nursery practices:							
Farmers using roof (%)	0	50	0	0	90	0	0
Average period (weeks)	6½	5	4½	7	5½	7½	11
Farmers fertilizing (%)	100	65	90	100	100	100	100
Type of fertilizer(s)*	Buffalo/chicken manure Urea	Sheep manure	Urea, NPK KCl, TSP, ZA	Cow manure Urea	Cow manure Urea	Cow/goat manure TSP, ZA	Cow manure Urea, TSP
Farmers using pesticides (%)	5	45	100	35	0	100	50
Type of pesticide(s)	Insecticides	Insecticides	Insecticides Fungicides	Insecticides	-	Insecticides	Insecticides

*Urea: 45-46 % N; ZA = Ammonium sulphate: 21 % N and 24 % SO_4; TSP = Triple super phosphate: 46 % P_2O_5; KCl: 60 % K_2O; NPK: 15 % N, 15 % P_2O_5 and 15 % K_2O.

a relay crop between shallots. One month old seedlings are pulled and replanted in the final plant pattern on the same shallot beds. The shallots are harvested another month later. Field visits during this period revealed that the circa two months old hot pepper crop suffered considerably from the shallot harvest, probably due to mechanical root damage.

Fertilizing practice (Table 2.3)

The use of manure and fertilizers in the field shows to be highly variable both among and within hot pepper areas. The number of applications of manure and/or fertilizers, disregarding the application of foliar fertilizers, varies between one and 18 times.

Application method and fertilizer use (Table 2.3). Before planting, fertilizers are placed in plant holes. In general, the basal fertilizers consist of stable manure, mineral fertilizers, ash of burnt rice straw or burnt kitchen waste. After planting, side-dressings are applied in different ways: (1) about 10 cm from the plant stems in holes that are covered with soil after application, (2) on the soil surface, about 10 cm from the plant stems, followed by irrigation, or (3) dissolved in water and poured around the plant base.

For the side-dressings, most farmers use nitrogen (N) in moderate to high dosages. In Area III, total N applied may amount up to 1000 kg/ha. In this area, farmers explained that they left the N fertilizer for one or more days on the soil before irrigating the crop, as otherwise 'the plant roots would get harmed'. The volatilization of N combined with frequent irrigation, which causes leaching, reduce the efficiency of N applications. Phosphorus (P) and potassium (K) fertilizers are not used by all farmers; often only either P or K is applied. Composite fertilizers such as NPK are rarely used, because they are relatively expensive (NPK costs between three to six times a mono-compound N, P or K fertilizer). Foliar fertilizers are quite popular and are usually applied, mixed with pesticides, using knapsack sprayers. These unbalanced fertilizing practices show that farmers lack basic knowledge of plant nutrition.

Crop health

The records of pests and diseases depend on their occurrence during field visits. The surveys were planned to take place at early harvesting stages, but irregular planting times caused some variation.

Major harmful agents. Farmers often used local and general terms, such as 'fruit rot', 'leaf curl', 'wilt', to indicate crop health problems. The harmful agents, mentioned in Table 2.4, were major causes of crop health problems observed during the exploratory surveys. Apparently, sucking insects, chewing insects, fruit flies, viruses, fruit rots and wilts caused major problems. These direct observations can be complemented with data derived from other LEHRI survey reports (Table 2.5). This table shows that caterpillars, mites, viruses,

Table 2.3. Fertilization practices in six major hot pepper production areas on Java, Indonesia.

Area	I	II	III	IV (Wet)	IV (Dry)	V	VI
# Applications	2-3	3-7	3-9	1-3	1-10	3-6	3-18
Quantity[1]							
N	Low-moderate	Low-high	High	Low	Low-high	Low-high	Low-high
P	Low-high	Moderate-high	Moderate	Low-moderate	Low-high	Low-high	Low-high
K	Low-high	Low-moderate	Moderate	Low-moderate	Low-high	Low-moderate	Low-moderate
Farmers applying (%)[2]:							
Stable manure	100	100	0	90	85	65	80
Urea	100	40	100	100	65	75	80
ZA	0	65	70	25	15	100	65
DAP	0	0	35	0	0	0	0
TSP	100	100	65	85	85	50	95
Kamas	0	0	40	0	0	0	0
KCl	55	55	65	15	50	0	30
NPK	5	45	65	0	0	25	35
Foliar fertilizer(s)	30	80	90	100	85	50	50

[1]Moderate = Dosages of applied fertilizers similar to LEHRI recommended dosage: 160 kg N/ha, 100 kg P/ha, 100 kg K/ha; Low = Dosages of applied fertilizers lower than LEHRI recommended dosage; High = Dosages of applied fertilizers higher than LEHRI recommended dosage.
[2]Urea = 45-46 % N; ZA = 21 % N; TSP = 46 % P_2O_5; KCl = 60 % K_2O; NPK = 15 % N, 15 % P_2O_5 and 15 % K_2O; DAP = Diammonium phosphate = 20 % N and 50 % P_2O_5; Kamas = 30 % K_2O.

Table 2.4. Commonly occurring crop health problems* in six major hot pepper production areas of Java, Indonesia.

Area	I	II	III	IV		V	VI
Survey season	Dry	Wet	Dry	Wet	Dry	Wet	Wet
Pests:							
Caterpillar (*Spodoptera* and *Heliothis* spp.)	-	+/-	++	+/-	+/-	-	+/-
Fruit fly (*Dacus* spp.)	-	+/-	+/-	++	-(++)	+	+/-
Sucking insect							
Aphid (*Myzus* spp., *Aphis* spp.)	+/-	-	-	+/-	+/-	+	+/-
Jassid (*Empoasca* spp.)	+/-	++	+/-	++	+/++	+	+
Thrips (*Thrips* spp.)	+	+/++	++	-	-	+/-	+/-
White fly (*Bemisia* spp.)	-	-	-	+/-	-	-	+/-
Mite (*Polyphagotarsonemus* spp.)	-	+	-	-	+	-	+/-
Diseases:							
Fruit rot (*Colletotrichum* spp.)	+(++)	++	+/-	-	+/++	-	+/-
Leaf spot (*Cercospora* spp.)	-	+/-	+/-	-	-	-	+
Virus (Several)	+	+/++	++	++	+/++	++	+/++
Wilt (*Pseudomonas* and *Sclerotium* spp.)	+/-	+/-	+/-	+/-	+/-	-(++)	+(++)

*- = not observed or not harmful; +/- = harmful in several locations; + = harmful in all locations; +/++ = harmful in all locations, very harmful in several locations; ++ = very harmful in all locations; (++) = very harmful according to the farmers, but not observed during surveys.

Table 2.5. Occurrence and harmfulness[1] of pests and diseases of hot pepper assessed during LEHRI surveys in different years and seasons at several locations in Indonesia.

Location	Year	Season	Area	Aphi	Cate	Ffly	Jass	Mite	Thri	Whit	Frot	Spot	Wilt	Viru	Nema	Rats[2]	Source
West Java:																	
Bekasi	1988	Wet	I	+	+	+	o	+	o	+	o	o	+	o	o	o	1
Bekasi	1988	Dry	I	-	+/-	o	o	+	+	o	++	+	+/-	++	o	o	2
Cirebon	1988	Wet	II	+	+	+	o	+	o	+	++	+	+	o	++	o	1
Jakarta	1988	Wet	-	+	+	++	o	+	o	+	o	o	o	++	o	o	1
Central Java:																	
Banyumas	1988	Wet	-	+/-	+	+/-	-	+	+	o	++	+	+/-	++	o	o	1
Brebes	1988	Wet	III	+/-	+	+/-	-	++	++	o	++	+	+/-	++	++	o	1
Brebes	1988	Wet-Dry	III	+	++	++	o	++	++	o	++	+	o	++	o	+	1
Brebes	1989	Wet	III	o	o	o	o	o	o	o	o	o	o	o	o	++	4
Demak	1988	Wet	-	+/-	+	+/-	-	+/-	+/-	o	++	+	+/-	++	++	o	1
Demak	1988	Wet-Dry	-	+	++	++	o	++	++	o	++	+	o	++	o	+	1
Semarang	1988	Wet	-	+/-	+	+/-	-	+	+	o	++	+	+/-	++	+	o	1
Tegal	1988	Wet	III	+	++	++	o	++	++	o	++	+	o	++	o	+	1
East Java:																	
Bojonegoro	1990	Dry	-	+	-	+/-	++	+	+/-	-	++	-	-	+	o	o	5
Madura	1990	Dry	-	-	-	+/-	-	-	+/-	-	-	+/-	-	++	o	o	5
Malang	1988	Wet	-	+/-	+	+/-	-	+/-	+/-	o	++	+	+/-	++	+	o	1
Sidoarjo	1988	Wet	-	+/-	+	+/-	-	+/-	+	o	++	+	+/-	++	o	o	1
Tuban	1988	Wet	IV	+/-	+	+/-	++	+/-	+/-	o	++	+	+/-	++	-	o	1
Sumatra:																	
Lampung	1988	Wet	-	+	+	++	o	+	o	+	o	++	+	++	+	o	1
Lampung	1988	Dry	-	+/-	+/-	o	o	+	+	o	+	++	+/-	++	o	o	2
Bali:																	
Several	1990	Wet	-	o	o	-	o	+/-	o	o	+/-	-	+/-	+/-	o	o	3
Lombok:																	
Several	1990	Wet	-	+/-	o	+/-	o	-	o	o	+/-	+/-	+/-	+	o	o	3

Sources: 1) Suhardi, 1988, unpublished LEHRI/ATA report; 2) Duriat *et al.*, 1988; 3) Duriat, 1990; 4) Vreden and Rochman, 1990; 5) Vos and Sumarni, 1990.

[1]o = no observations made; - = not observed or not harmful; +/- = present and/or harmful in several locations; + = present and/or harmful in all locations; +/++ = harmful in all locations, very harmful in several locations; ++ = very harmful in all locations.

[2]Aphi=Aphid; Cate=Caterpillar; Ffly=Fruit fly; Jass=Jassid; Mite=Mite; Thri=Thrips; Whit=White fly; Frot=Fruit rot; Spot=Leaf spot; Wilt=Wilting; Viru=Virus; Nema=Nematode; Rats=Rat.

fruit rots and leaf spots are the most important of the observed harmful agents. Considering Tables 2.4 and 2.5, a list of major hot pepper pests and diseases should include caterpillars, fruit flies, mites, sucking insects, fruit rots, leaf spots, viruses and wilts.

Crop protection practice and pesticide use (Table 2.6). Chemical control appeared to be the major method of crop protection. Except for weeding, mechanical control measures such as hand picking of caterpillars were rare. Roguing was not practised. The intensity of pesticide use was often explained to be depending on farmers' financial situations. In all areas except III, at least a few farmers did not apply any pesticides. 'Lack of money' was their major motive for not spraying.

Pesticides were applied with standard knapsack sprayers, using cone type nozzles. The frequency of applying pesticides varied enormously, between once per two months to every other day. Insecticides were most popular, while fungicides were less often used and acaricides only rarely applied. Herbicide application was exceptional, as hand weeding was common practice.

Generally speaking, fruit rot and leaf spot diseases were most prevalent during rainy periods. The seasonality of harmful agents was, however, not reflected in the package of pesticides used, as fungicides and insecticides were applied during both dry and rainy seasons. Farmers seemed to be unaware of specific effects of pesticides. They often did not distinguish insecticides from fungicides, or even from foliar fertilizers, calling all of them *obat* (Eng.: medicine). The information about best brands, dosages and mixtures of pesticides were obtained from pesticide retailers or from fellow farmers. Precautions to be taken during spraying were neglected. Protective clothing was considered too warm and pesticide packing material was disposed in or around fields.

When examining the pesticides applied (Table 2.7), many of them are not recommended for vegetables but for other crops such as rice. Of the 58 formulations mentioned by farmers, 57 (98 %) are listed in the Indonesian pesticide guide (Anonymous, 1990b), but only 19 (33 %) as recommended for hot pepper. The misuse of pesticides in several areas becomes even more evident when the mixing of compounds is considered. In Area III, farmers sprayed cocktails consisting of two to nine compounds (Table 2.8). In that area, each farmer applied his own specific mixture, from time to time adding other 'promising' pesticides. In a survey on pesticide use by Van der Noll and Savitri (1989), comprising 36 vegetable farmers in the East Java regency Malang (high elevation vegetable production area), high inputs of pesticides were also found in hot pepper cultivation. The average application interval was 3 days and mixing of two to six pesticides in a cocktail appeared to be common practice. It appears that misuse of chemical control, including under- and over-utilization of pesticides, exists in many areas of hot pepper production on Java.

Table 2.6. Pesticide use by farmers in six major hot pepper production areas on Java, Indonesia.

Area	I	II	III	IV	IV	V	VI
Production season	Dry	Wet	Dry	Wet	Dry	Wet	Wet
# Applications	0-20	0-10	13-40	0-20	0-20	0-3	0-24
Frequency of applications*	Low-Moderate	Low-Moderate	High	Low-Moderate	Low-Moderate	Low	Low
Farmers applying (%)							
Fungicides	35	50	80	10	15	50	35
Insecticides	95	100	100	100	85	75	35
Acaricides	35	0	10	0	0	0	0
Cocktails of compounds	0	95	100	10	15	50	35

*Moderate = Frequency of application once a week; Low = Frequency of application less than once a week; High = Frequency of application more than once a week.

Table 2.7. Pesticides applied by farmers in six major hot pepper areas on Java, Indonesia.

Active ingredient	Tradename(s)	Recommended*	Recommended on other crops*
Acephate	Orthene	no	*Aphis, Heliothis, Spodoptera*
	Sematron	yes	*Thrips*
Bendiocarb	Garvox	no	-
Benomyl	Benlate	no	*Cercospora, Fusarium*
Beta cyfluthrin	Buldok	yes	*Bactrocera, Myzus, Spodoptera*
BPMC (= Fenobucarb)	Kiltop	no	*Heliothis, Spodoptera*
	Baycarb, Hopcin, Indobas	no	-
Captafol	Difolatan	-	-
Carbaryl	Sevin	no	*Empoasca, Heliothis, Spodoptera, Thrips*
Carbofuran	Furadan	no	*Heliothis, Meloidogyne, Spodoptera*
	Indofuran	no	-
Cartap hydrochloride	Padan	no	-
Chlorfluazuron	Atabron	yes	*Spodoptera*
Chlorothalonil	Daconil	no	*Cercospora, Colletotrichum*
Chlorpyrifos	Dursban	yes	*Myzus*
Cyfluthrin	Baythroid	no	*Heliothis*
Cyhalothrin	Matador	yes	*Spodoptera*
Cypermethrin	Fenom, Ripcord	yes	*Spodoptera*
	Sherpa	no	*Heliothis, Spodoptera*
Deltamethrin	Decis	no	*Heliothis, Spodoptera*
Diazinon	Basudin	no	*Aphis, Spodoptera*
	Diazinon	no	*Heliothis, Spodoptera*
Diflubenzuron	Dimilin	yes	*Spodoptera*
Dimethoate	Perfekthion	no	*Aphis, Empoasca*
Endosulfan	Thiodan, Fanodhan	no	*Heliothis, Spodoptera*
	Dekasulfan	yes	*Thrips*
Ethoproxifen	Trebon	no	*Spodoptera*
Fenpropathrin	Meothrin	yes	*Spodoptera*
Fenthion	Lebaycid	no	*Aphis, Empoasca, Spodoptera*
Flufenoxuron	Cascade	no	*Spodoptera*
Isoprothiolane	Fujiwan	no	-
Isoxathion	Karphos	no	*Spodoptera*
Mancozeb	Dithane	no	*Cercospora, Colletotrichum*
	Trimiltox, Vondozeb	no	-
Metham-sodium	Vapam	no	*Meloidogyne*
Methamidophos	Tamaron	yes	*Spodoptera*
Methidathion	Supracide	yes	*Bactrocera, Myzus*
Methiocarb	Mesurol	yes	*Thrips*
Methomyl	Lannate	no	*Empoasca, Heliothis, Spodoptera, Thrips*
MIPC (= Isoprocarb)	Mikarb	no	*Spodoptera*
	Mipcin	no	-
Monocrotophos	Azodrin	no	*Empoasca, Heliothis, Spodoptera*
	Gusadrin	no	*Heliothis, Spodoptera*
Phenthoate	Elsan	no	-
Phosalone	Zolone	no	*Aphis, Heliothis, Spodoptera*
Profenofos	Curacron	yes	*Bactrocera, Myzus, Spodoptera*
Propargite	Omite	yes	*Tetranychus*
Propineb	Antracol	yes	*Cercospora, Colletotrichum*
Prothiofos	Tokuthion	yes	*Bactrocera, Myzus, Spodoptera, Thrips*
Pyridaphention	Ofunack	no	*Spodoptera*
Teflubenzuron	Nomolt	yes	*Spodoptera*
Triazophos	Hostathion	no	*Heliothis, Spodoptera, Meloidogyne*
Triflumuron	Alsystin	yes	*Bactrocera, Myzus, Spodoptera*

*Against hot pepper phytophages (Source: Anonymous (1990); - = not in Anonymous (1990)).

Table 2.8. Pesticide cocktails most frequently applied by 24 farmers in the major hot pepper production area of Brebes (Area III) on Java, Indonesia*.

Farmer code:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Active ingredients																									Frequency
Acephate	+										+														2
Bendiocarb																						+			1
Captafol																	+								1
Cartap hydrochloride						+																			1
Cyfluthrin	+	+	+								+	+	+			+			+						8
Cypermethrin				+																					1
Deltamethrin			+		+	+		+					+	+		+		+			+	+			10
Diazinon								+																	1
Dimethoate		+	+	+								+		+							+	+			7
Endosulfan							+	+					+		+	++						+			7
Flufenoxuron			+	+			+										+								4
Mancozeb																				+					1
Methamidophos			+					+	+	+	+	+			+	+		+	+	+		+	+	+	14
Methidathion							+	+													+				3
Methiocarb	+																								1
Monocrotophos								+										+							2
Phosalone							+								+		+	+							4
Profenofos						+		+	+	+					+		+		+	+			+	+	10
Propargite						+															+				2
Propineb			+	+	+	+		+	+	+			+	+		+	+		+	+	+			+	15
Prothiofos	+		+		+	+		+						+	+							+	+		9
Triazophos	+		+		+								+	+									+		6
# Compounds/cocktail:	5	2	8	4	4	6	4	9	3	3	3	3	5	5	5	6	5	4	4	4	5	6	4	3	
Total # of compounds used per farmer**:	5	3	8	4	7	9	14	10	6	8	5	5	5	5	18	10	9	11	6	11	6	7	7	3	

*Source: LEHRI 1991 on-farm case study on among others pesticide use of hot pepper farmers in the regencies Brebes and Tegal.
**Not necessarily all in one pesticide cocktail.

2.4 Discussion and conclusions

The results of the exploratory surveys show that hot pepper crop management, presently applied by farmers on Java, is variable. Only few practices are uniform in all areas, such as seed production and transplanting practices. Most practices differ from area to area, each having impacts on crop performance and crop health. Most striking are differences in fertilizer and pesticide use.

Considerations on sustainability

In Area III farmers apply high amounts of nitrogen fertilizer and pesticides. In Area V and VI, pesticide use is low and in Area I and IV (wet season), nitrogen use is low. Excessive use of external inputs results in non-sustainable agriculture (Reijntjes *et al.*, 1992). Low quantities of artificial inputs, on the other hand, may lead to over-utilisation of the land and hence to non-sustainable agriculture too. It is, however, improper to classify the hot pepper production Area III as high- and the other areas as low-external-input agricultural systems (HEIA and LEIA in Reijntjes *et al.*, 1992), because external inputs such as fuel consuming mechanisation or certified seed are unknown in all areas I-VI. Instead, Area III could be classified as high agro-chemical input area and the five other areas as low agro-chemical input areas. The high agro-chemical input area (Area III) distinguishes itself from the other areas in the relay cropping system, the raised beds and deep furrows system, the high plant density, the absence of use of manure, the high dosages of nitrogen fertilizers, the intensive use of pesticides with application of complex pesticide-cocktails and the high yield.

Crop health and relations to ICM components

Cultural practices. The impact of cultural practices on disease was discussed by Palti (1981). Effects of fertilizer use in relation to crop health has especially been studied for nitrogen. According to Huber (1991), N influences crop health as it promotes crop growth, delays maturity, and is essential for production of plant constituents that are correlated with host plant resistance or susceptibility, such as amino acids, total N, C/N ratios, etcetera. Following Palti (1981) and Huber (1991), Table 2.9 illustrates possible effects of cultural practices, whether or not applied by hot pepper farmers on Java, on crop health. Table 2.9 symbolizes the disease tetrahedron of Zadoks and Schein (1979) and illustrates the holistic approach of ICM. This general approach is to be related to hot pepper crop health problems as encountered during surveys. In this discussion, the use of resistant cultivars should be included as a solution to crop health problems in the long run. Development of resistant cultivars is urgently needed. Habitat management, the establishment of refuges for beneficials, plays a role in enhancing biological control activities.

Table 2.9. Effects of cultural practices on crop health through factors that are related to the disease tetrahedron.

Factors related to crop health / Cultural practices	PARASITE			HOST		ENVIRONMENT				
	Initial population	Population growth rate	Population survival	Genetic resistance	Non-genetic resistance	Temperature	Water availability	Nutrient availability	Relative humidity	Beneficials**
HUMAN										
Sanitation	+	+	+							
Tillage	+	+	+							
Rotation	+	+	+							
Crop nutrition		+			+			+		+
Irrigation		+	+		+		+		+	
Season choice	+	+	+				+		+	+
Seed production	+		+							
Nursery	+	+			+	+	+	+	+	
Transplanting	+	+			+		+	+		
Multiple cropping		+			+		+	+	+	+
Cultivar choice				+*						
Crop duration		+	+		+		+	+		
Plant distance		+				+	+	+	+	+
Mulching		+				+	+	+		+
Chemical control	+	+	+		+					+
Habitat management										+

* In case resistant cultivars are available
** Natural enemies, antagonists, competitors.

Virus diseases. As indicated by field observations, viruses cause major crop health problems in all visited areas. Sanitation measures such as destruction of crop residues could play a major role. Another important method to control primary infection of the crop is the production of virus-free seed and the raising of virus-free transplants. Use of certified seed and the application of appropriate nursery practices such as use of sub-soil and screen cover, contribute to the control of the initial inoculum of mechanically and aphid-transmitted viruses. There is not much to be expected from a change of planting time, as virus vectors, mainly aphids, occur year-round. However, a long period in a screened nursery could delay primary aphid-transmitted virus infection. Later virus inoculations seem to have less effect on *Capsicum* fruit yield than earlier inoculations (Agrios *et al.*, 1985; Ang *et al.*, 1980). After planting in the field, vector repellents (e.g. light-reflecting mulches) or trapping (e.g. yellow sticky boards) devices might slow virus epidemics down (Mandahar *et al.*, 1990; Cohen and Marco, 1973).

Insect pests and mites. The arthropod pests listed in the Tables 2.5 and 2.6 are mostly polyphagous pests. Multiple cropping and/or rotation with other species is therefore not expected to solve the problem. Instead, use of screen-protection in the nursery and application of insect repellant devices could reduce the initial population and population build-up. Insect traps with attractants could be applied to monitor and reduce insect populations (Shorey, 1991). Field sanitation measures, including tillage and destruction of crop residues, might reduce initial pest populations. In alfalfa, field sanitation has proven to successfully reduce initial insect pest populations and the final damage (Stern, 1991). Hand picking of caterpillars and removal of fruit fly infected fruits seem to be unpopular among farmers, but could contribute to the reduction of pest population build-up. In Brebes (Area III), shallot farmers conduct hand picking of *Spodoptera* egg clusters or caterpillars as a component of pest control (Buurma and Nurmalinda, 1992). Non-chemical crop protection could benefit population growth of natural enemies as an advantageous side-effect. Seed treatment with a systemic pesticide (Jeffs, 1986) or application of a systemic granular pesticide in the plant holes at transplanting could reduce initial parasite population build-up. Hence, relatively small quantities of chemicals could have major influence on the establishment of a healthy crop. More attention for balanced crop nutrition should benefit non-genetic crop resistance and reduce population build-up of phytophagous insects and mites.

Fungal and bacterial diseases. Disease-free seed could be seed-coated with antagonists or with systemic fungicides and sown in steam-sterilized soil or sub-soil to avoid primary infection (Cook, 1981; Jeffs, 1986). Other applicable solutions to hot pepper crop health problems, related to fungal or bacterial diseases, are cited from Palti (1981). The main source of infection of many fungal and bacterial diseases, such as *Cercospora* leaf spot and bacterial wilt, is the soil. Sanitation measures, such as destruction of crop residues, tillage, avoidance of contaminated irrigation water, and crop rotation are therefore major tools to reduce initial inoculum. The plant density in the field could be adjusted as to reduce relative humidity in the micro-environment. Both multiple cropping with non-hosts and balanced crop nutrition might reduce disease build-up. Mulching with paper or plastic sheets might contribute to reduction of soil splash and thus to a delay in disease epidemics. Secondary infection could be delayed by the removal of diseased/infested plants or plant parts (roguing).

Components of hot pepper ICM. In conclusion, the following ICM components are selected for research to improve hot pepper crop health in Java on a short term: improvement of nursery practices, use of mulch, balancing crop nutrition, optimizing plant density, hand picking of caterpillars and infected plant parts, use of clean irrigation water, use of insect traps, multiple cropping practices and optimisation of crop rotation. Breeding for resistance should be included as long term strategy in ICM research.

Prospects for the Indonesian situation

Research and extension efforts should be in line with farmers' needs and pay attention to farmers' socio-economic situations. Farmers' situations differ from one area to another, but a pattern can be discerned. In general, the production capacity of each farmer depends on external factors, such as information about improvements of crop health, strong fluctuations of market prices, presence of irrigation canals, availability of clean seed and/or resistant cultivars. Many of the interviewed farmers explained that their knowledge on crop health improvement was limited due to lack of information. The lack of knowledge on symptomatology undoubtedly plays a role in pesticide misuse. The ICM components, mentioned in the above conclusion, are expected to be readily adopted by farmers as these are acceptable modifications of present practices. The selected ICM components should be investigated at experimental stations, in order to test their benefits, supplemented by on-farm trials in cooperation with farmers and extension staff. Eventually, farmers should evaluate the value of ICM components before recommendations are promoted, conform the 'on-farm client-oriented research' (OFCOR) approach (Merrill-Sands and McAllister, 1988). Although concentrating on farmers' expertise too, the OFCOR approach differs from the ecological research approach which has proved successful in the Indonesian integrated pest management programme on rice (Kenmore, 1991). Attention for non-chemical crop protection in rotating commodities is expected to generate more sustainable agro-ecosystems.

Chapter 3

Pests and diseases of hot pepper (*Capsicum* spp.) in tropical lowlands of Java, Indonesia

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Submitted.

Abstract: Major hot pepper (*Capsicum* spp.) pests on Java, Indonesia, are cotton boll worm, cotton jassid, oriental fruit fly, thrips, tropical army worm, yellow tea mite, and major diseases are anthracnose, bacterial wilt, *Cercospora* leaf spot, southern blight and viruses. Monitoring of pests and diseases in the field is based on incidence and/or severity observation keys. Vegetative stages of hot pepper are injured by cotton jassid, thrips, tropical armyworm and yellow tea mite. Bacterial wilt, *Cercospora* leaf spot, southern blight and viruses are most harmful during and after fruit set. Anthracnose, cotton boll worm and oriental fruit fly are harmful during fruiting and harvesting stages. As phytophages occur simultaneously, applied crop protection research should concentrate rather on the crop and the complex of its harmful agents than on an individual harmful agent.

3.1 Introduction

In Indonesia, about 64 % of all hot pepper (*Capsicum* spp.) is produced on the island of Java. On Java, hot pepper is the most important vegetable crop, in terms of hectareage (1989: 94,000 ha) and production value (1989: $179*10^9$ IDR ≈ $89*10^6$ US$). Hot pepper is a typical tropical low elevation vegetable as 69 % of the planted area is located below 200 m asl. The national average hot pepper yield is low, 2.8 t/ha in 1989. Poor crop health is the major problem in hot pepper production (Chapter 1).

Phytophages of hot pepper in Indonesia were described in the handbooks by Dammerman (1919), Kalshoven (1951) and Semangun (1989). Dammerman (1919) thoroughly described arthropods and nematodes harmful to agriculture in Indonesia, but did not deal specifically with hot pepper. The following harmful organisms of solanaceous crops were mentioned: *Heterodera radicicola*, *Opatrum* spp., *Agrotis* spp., *Leucinodes orbonalis*, *Heliothis obsoleta*, *Papilio agamemnon*, *Epilachna* spp., *Brachyplatys nigriventris*, *Coptosoma cribarium*, *Nezara viridula*, *Dacus ferrugineus* (synonymous with: *Bactrocera dorsalis*) and *D. cucurbitae*. Kalshoven (1951) classified *Empoasca* spp., *Dacus ferrugineus, Spodoptera exigua, Tarsonemus* spp., thrips, shield bugs and aphids as the most important pests of hot pepper. Semangun (1989) described the following organisms causing disease on hot pepper, *Cercospora capsici, Gloeosporium piperatum, Colletotrichum capsici, Phytophthora* spp., *Pseudomonas solanacearum*, cucumber mosaic virus (CMV), tobacco etch virus (TEV), tobacco rattle virus (TRV) and potato virus A (PVA). A large number of other fungi, bacteria and viruses were listed as causal agents of less important diseases. Illustrated descriptions of hot pepper phytophages were published recently by the Asian Vegetable Research and Development Centre (AVRDC) Taiwan (Black *et al.*, 1991), and by the Lembang Horticultural Research Institute (LEHRI) Indonesia (Van Vreden *et al.*, 1994). Estimates of yield losses due to major hot pepper phytophages in Indonesia were reported in Chapter 1.

This chapter presents a list of phytophagous organisms found in hot pepper production areas at low elevations on Java. The importance of each phytophage in terms of incidence and injury is indicated. The symptoms caused by 11 major pests and diseases are described. Methods for assessment of pest and disease incidence and/or severity in the field are included. The crop stages during which injury may occur are indicated. Phenological stages vulnerable to particular pests and diseases are shown, to indicate when appropriate crop protection actions should be taken.

3.2 Methodology

Exploratory surveys were carried out to make an inventory of crop management methods in important low elevation production areas on Java (Chapter 2). During these surveys, crop health problems in different parts of Java were registered. Survey results were supplemented by field observations. The classification into major, occasional and minor crop health problem is based upon the incidence of and injury by phytophages in fields as observed during field visits and as mentioned by farmers and/or extension officers in hot pepper production areas.

Phytophagous arthropods and their natural enemies were collected, preserved and identified at LEHRI in Indonesia or sent for identification to the Plant Protection Service (PD-DLO) in the Netherlands. Pathogenic fungi and bacteria were isolated, cultured and used for inoculation experiments to describe symptoms under greenhouse conditions. Koch's postulates were tested at Wageningen Agricultural University (WAU) and the Centre for Plant Breeding and Reproduction Research (CPRO-DLO), in the Netherlands, with *Cercospora* spp., *Choanephora* spp., *Cladosporium* spp., *Colletotrichum* spp., *Curvularia* spp., *Fusarium* spp., and *Sclerotium* spp., on a popular Indonesian hot pepper landrace ('Jatilaba'). Purified cultures were sent to PD-DLO for identification. Virus samples were obtained by collecting symptom bearing leaf material in the field. Virus infected leaves were cut in small pieces, dried and stored over calcium chloride at 4 °C (McKinney and Silber, 1968). Samples were serologically analyzed by enzyme-linked immunosorbent assay (ELISA) at LEHRI and/or at AVRDC in Taiwan. Samples, containing serologically detected viruses, were subjected to an electron microscopic examination using the technique of immunosorbent electron microscopy with decoration (Milne and Lesemann, 1984) at the Research Institute for Plant Protection (IPO-DLO) and immuno-gold labelling at WAU (Van Lent and Verduin, 1985), in the Netherlands, to confirm the serological identifications. The information concerning pathogenic nematodes and rodents on hot pepper was obtained from previous investigations at LEHRI and the Bogor Research Institute for Food Crops (BORIF) in Indonesia.

A time table of crop phenological stages was derived from 11 field trials conducted during 1989-1992 at low elevation LEHRI experimental sites in Subang (West Java, 110 m asl) and Brebes/Tegal (Central Java, 10 m asl). Per trial, field observations on pest and disease occurrences were related to the crop phenological stages.

3.3 Hot pepper pests and diseases

Pests and diseases of hot pepper found at low elevations, are listed in Table 3.1. Figure 3.1 illustrates which plant parts are affected by the phytophages mentioned in Table 3.1. The important harmful agents (++ in Table 3.1) are described in the following sections, with special attention for symptomatology and field assessment methods.

Pests

*Cotton boll worm (*Heliothis armigera *Hübner; Lepidoptera: Noctuidae) (Figure 3.2).* Larval stages of the cotton boll worm pierce the fruit wall and feed on the inner part of immature hot pepper fruits. The injury consists of typical clear cut entrance holes in fruits. The fruit does not decay. After opening an injured fruit, feeding injury on the inner side of the fruit and larval excrements can be observed. The cotton boll worm pupates in the soil. After mating, female moths lay single eggs on host plants. The cotton boll worm is a polyphagous pest, occurring also on cotton, maize, sorghum, tobacco, tomato and many other crops (Goodyer, 1987). Sources of infestation are the single eggs, deposited on host plants. Adult boll worms can migrate over distances of 200 km or more (Drake, 1991).

To estimate population densities of adults and larvae, Titmarch *et al.* (1991) described different field observation techniques, of which 'direct observation' of plants and 'sweep netting' appear most practical. *Heliothis* larvae are easily confused with *Spodoptera* larvae. Light or pheromone traps may be useful to monitor adult populations of the cotton boll worm (Gregg and Wilson, 1991). The assessment of damage is symptom based and consists of counting the injured fruits at harvest. Total crop damage can be calculated by cumulating injured numbers of fruits over all harvest dates, and expressing the sum as a percentage of the total number of harvested fruits.

*Cotton jassid (*Empoasca lybica *de Bergevin and Zanon; Hemiptera: Cicadellidae) (Figure 3.3).* Cotton jassids cause white dots, due to puncture feeding, mainly on the upper sides of leaves. In case of a heavy infestation the foliage is covered with these white dots. When disturbed, the jassids rapidly jump away. Cotton jassids have a wide host range, including cotton, cucurbits, eggplant, tomato, potato, and others (Kranz *et al.*, 1977). The pest is assumed to spread by active migration from one host crop or from weeds to another host crop.

Observations during surveys indicated that cotton jassids were more abundant during dry periods and that the insect was most frequently found on young leaves. A field key for injury assessment is proposed (Table 3.2). The key could not be tested as epidemics did not occur at LEHRI experimental sites.

Table 3.1. Low elevation hot pepper pests and diseases and their relative importance in Java, Indonesia (++ = major, + = occasional, o = minor, - = secondary pest or disease).

Common names: English	Common names: Indonesian	Scientific name	Confirmation by*	Importance
Arthropods				
Balsam hawk moth	Ulat kuda	*Theretra oldenlandiae* Fabricius	Romeijn, PD-DLO 1993	o
Cotton aphid	Kutu daun	*Aphis gossypii* Glover	Aukema, PD-DLO 1993	+
Cotton boll worm	Ulat buah	*Heliothis armigera* Hübner	Van Vreden, LEHRI 1990	++
Cotton jassid	Wereng	*Empoasca lybica* de Bergevin & Zanon	-	++
Green snout beetle	-	*Hypomeces squamosus* Fabricius	-	o
-	Ulat euproctis	*Euproctis virguncula* Walker	-	o
Oriental fruit fly	Lalat buah	*Bactrocera dorsalis* Hendel	De Goffau, PD-DLO 1990	++
Southern green stink bug	Kepik hijau	*Nezara viridula* Linnaeus	Aukema, PD-DLO 1993	o
Thrips	Trips	*Thrips parvispinus* Karny	Vierbergen, PD-DLO 1989	++
Tropical army worm	Ulat grayak	*Spodoptera litura* Fabricius	Van Vreden, LEHRI 1990	++
Whitefly	Lalat putih	*Aleurodicus dispersus* Russell	Jansen, PD-DLO 1993	+
Yellow tea mite	Tungau kuning	*Polyphagotarsonemus latus* Banks	Magevsky, UVA 1992	++
Bacteria				
Bacterial wilt	Layu bakteri	*Pseudomonas solanacearum* (Smith) Smith	Van der Tuin, PD-DLO 1994	++
Soft rot	Busuk basah	*Erwinia carotovora*	-	-
Fungi				
Anthracnose fruit rot	Antraknosa	*Colletotrichum capsici* (Sydow) Butler & Bisby	Veenbaas, PD-DLO 1992	++
		C. acutatum Simmonds ex Simmonds	Meffert, PD-DLO 1994	
		C. gloeosporioides (Penzig) Penzig & Saccardo)	-	
Blossom mold	Sentik	*Choanephora cucurbitarum* (Berkeley & Ravenel) Thaxter	Meffert, PD-DLO 1994	+

Cercospora leaf spot	Bercak daun	*Cercospora capsici* Heald & Wolf	Veenbaas, PD-DLO 1992	++
Curvularia fruit rot	Busuk buah	*Curvularia lunata* (Wakker) Boedijn	Veenbaas, PD-DLO 1992	+
Fusarium fruit rot	Busuk buah	*Fusarium semitectum* Berkeley & Ravenel	Veenbaas, PD-DLO 1992	o
		F. longipes Wollenweber & Reinking	Veenbaas, PD-DLO 1992	o
Southern blight	Busuk pangkal/ batang putih	*Sclerotium rolfsii* Saccardo	Veenbaas, PD-DLO 1992	++
-	-	*Cladosporium cladosporioides* (Fresen) de Vries	Veenbaas, PD-DLO 1992	-
Nematodes				
Reniform nematode	-	*Rotylenchulus reniformis* Linford & Oliveira	Netscher, ORSTOM 1989	+
Root knot nematode	-	*Meloidogyne incognita* Chitwood	Marwoto & Widjaja, LEHRI 1991	+
Rodents				
Paddy-field rat	Tikus sawah	*Rattus argentiventer* Robinson & Kloss	Rochman, BORIF 1990	+
Viruses (Serologically identified)				
Cucumber mosaic	-	CMV	Green, AVRDC 1989	++
Chilli veinal mottle	-	CVMV	Green, AVRDC 1989	++
Pepper mild mottle	-	PMMV	Green, AVRDC 1989	+
Potato X	-	PVX	Green, AVRDC 1989	+
Potato Y	-	PVY	Green, AVRDC 1989	+
Tomato mosaic	-	ToMV	Green, AVRDC 1989	+

*Acronyms:
AVRDC = Asian Vegetable Research and Development Center, Taiwan.
BORIF = Bogor Research Institute for Food crops, Indonesia.
LEHRI = Lembang Horticultural Research Institute, Indonesia.
ORSTOM = Organisation de Recherches Scientifiques et Techniques d'Outre-Mer, France.
PD-DLO = Plant Protection Service, the Netherlands.
UVA = University of Amsterdam, the Netherlands.

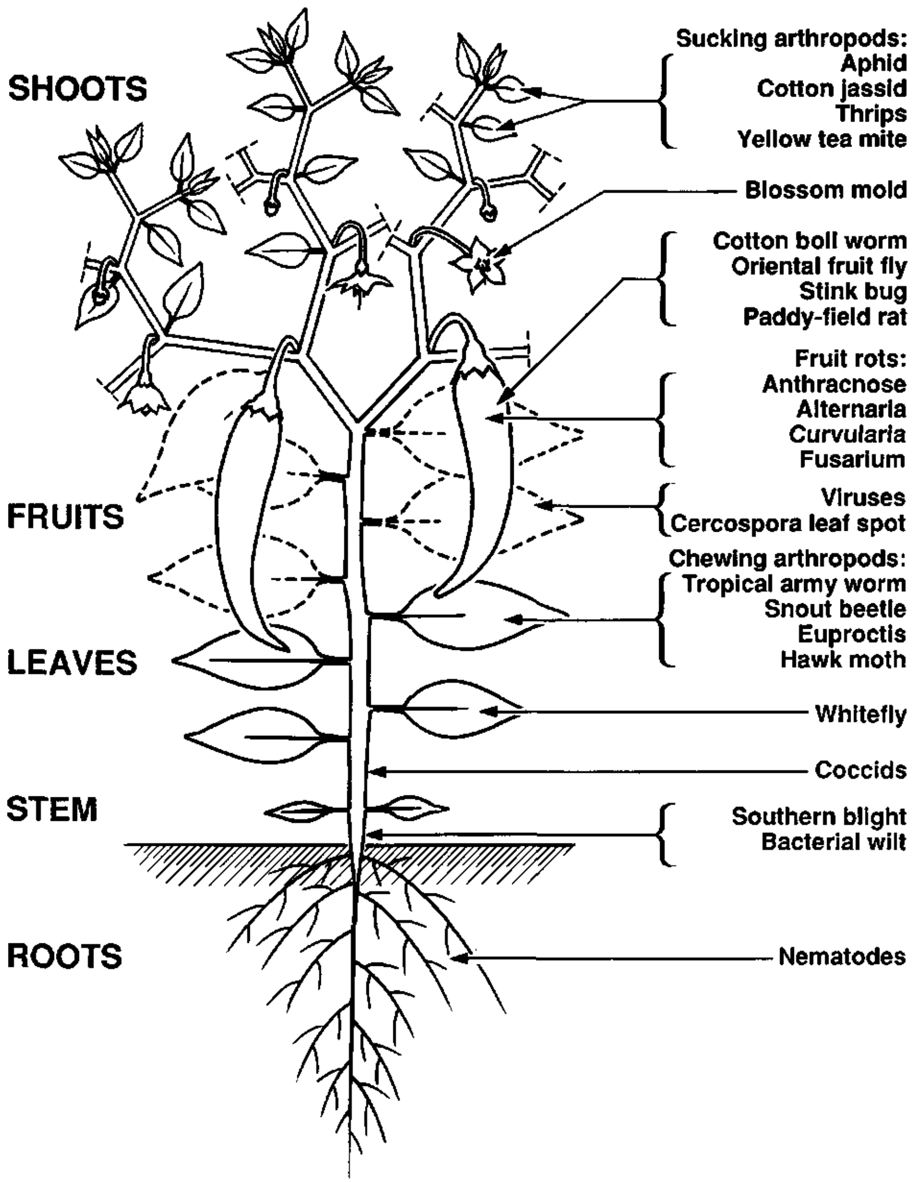

Figure 3.1. Schematic presentation of a hot pepper plant and its phytophages. Drawing by Mr. P.J. Kostense, WAU the Netherlands.

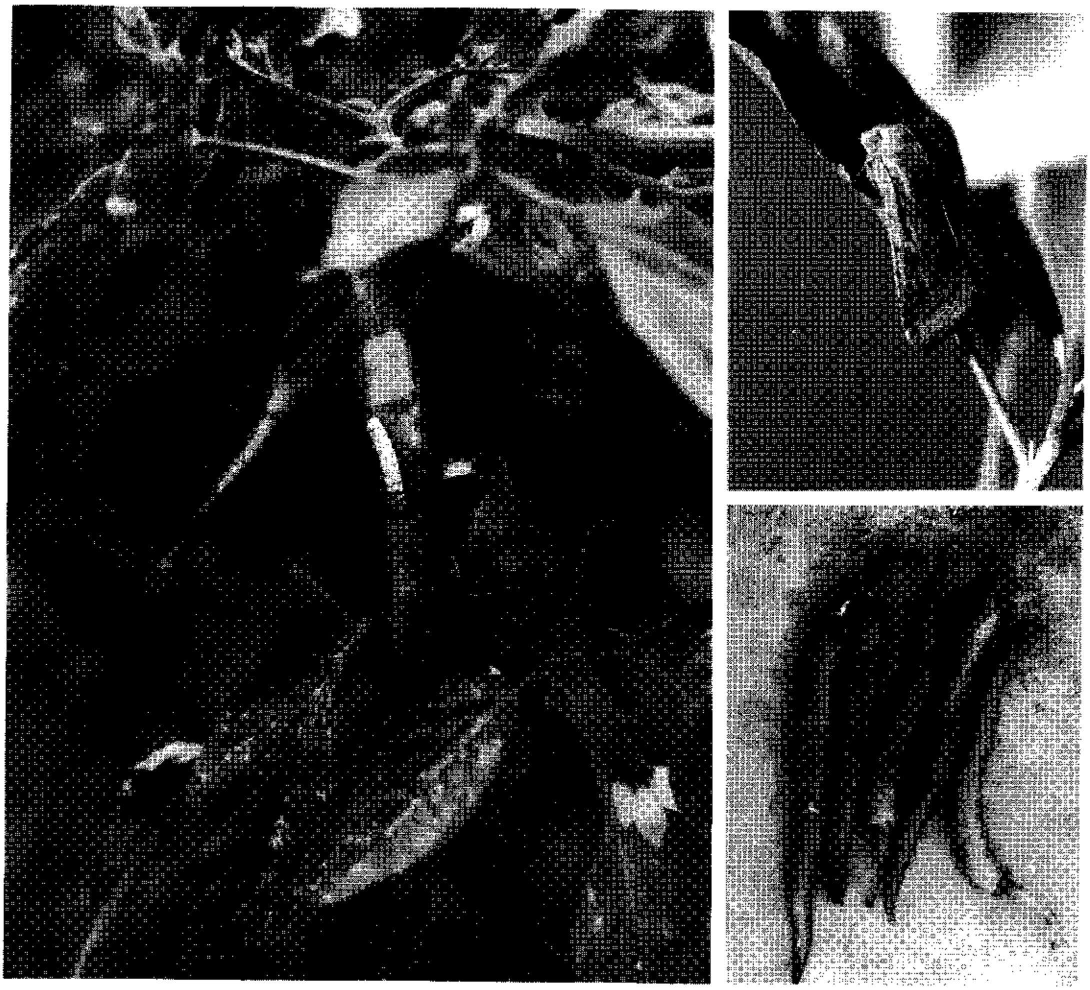

Figure 3.2. Cotton boll worm (*Heliothis armigera*). Left: feeding larva. Above right: adult moth. Below right: hot pepper fruit injury.

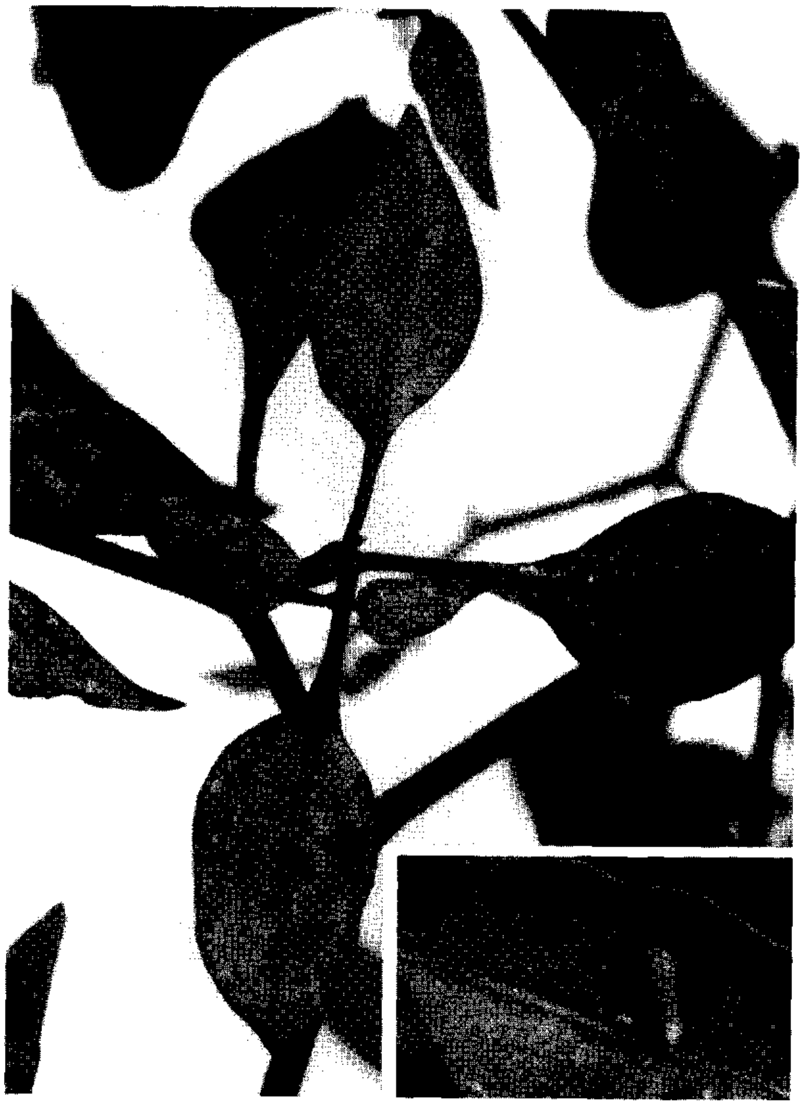

Figure 3.3. Cotton jassid (*Empoasca lybica*). Feeding injury on hot pepper. Inset: adult jassid.

Table 3.2. Proposed field key to assess cotton jassid injury in a hot pepper crop.

Score	Description
0	No symptoms.
1	Less than 25 % of the plants show groups of white dots, mainly on young leaves.
2	25 To 50 % of the plants have white dots on the foliage.
3	50 To 75 % of the plants have white dots on the foliage.
4	More than 75 % of the plants have white dots on the foliage.
5	All plants have numerous white dots on the foliage.

*Oriental fruit fly (*Bactrocera dorsalis *Hendel; Diptera: Tephritidae) (Figure 3.4).* Oriental fruit fly injury is characterized by the occurrence of waterlogged, decaying fruits. Females deposit eggs in the fruits. The eggs hatch and the larvae feed inside the fruit. After opening an infected fruit, one or more larvae can be found. Young larvae tend to crawl back into the fruit flesh, but mature larvae move and jump actively in search of soil as a medium for pupation. The oriental fruit fly is a polyphagous pest, attacking many kinds of fleshy fruits. In Indonesia the main hosts of the oriental fruit fly, besides hot pepper, are banana, mango, orange and star fruit (Tjiptono, cited in Koyama, 1989). Adults fly actively and can spread over large distances, up to 50 km (Iwahashi, 1972).

Different methods were applied to assess population density and injury. Oriental fruit fly populations were monitored by use of a lure trap (after Steiner, 1957) with a few drops of both an attractant (methyl eugenol) and an insecticide (monocrotophos) on a cotton boll. The trap was positioned at crop canopy level and the cotton boll with bait and poison was replaced every one or two weeks. Methyl eugenol only lures male fruit flies, possibly due to imitation of food odour if males have other food requirements than females (Cunningham, 1989). The damage assessment method consisted of counting the infected fruits at harvest and cumulating these over all harvest dates. The damage is the number of infected fruits relative to the total number of harvested fruits, in %.

Oriental fruit fly particularly occurs during rainy periods, as do other fruit fly species (Bateman, 1972). Monitoring male flies during field experiments in Subang from 1990 until 1992 resulted in an average of 725 male fruit flies per month during two rainy seasons and of 250 flies per month during two dry seasons. Besides *Bactrocera dorsalis, B. umbrosus* Fabricius was occasionally trapped in the lure trap. As this species was not reared from infected hot pepper fruits it was not considered a hot pepper pest.

Thrips parvispinus *Karny (Thysanoptera: Thripidae) (Figure 3.5).* Kalshoven (1951) referred to *Isoneurothrips parvispinus* Karny (synonymous with *T. parvispinus* Karny) as tobacco thrips. As this common name is also in use for other thrips species it will not be used here. Little is known about the biology of *T. parvispinus*. According to Palmer *et al.* (1989) this species becomes increasingly common in the Pacific region. *T. parvispinus* prefers to feed on young leaves. Severe outbreaks occur during lengthy dry periods. The

Figure 3.4. Oriental fruit fly (*Bactrocera dorsalis*). Above f.l.t.r.: pupa, ♀ and ♂ adult fly. Below left: adult fly probing into green hot pepper fruit. Centre right: adult *Opius* parasitoid. Below right: fruit fly larva taken from infected hot pepper fruit.

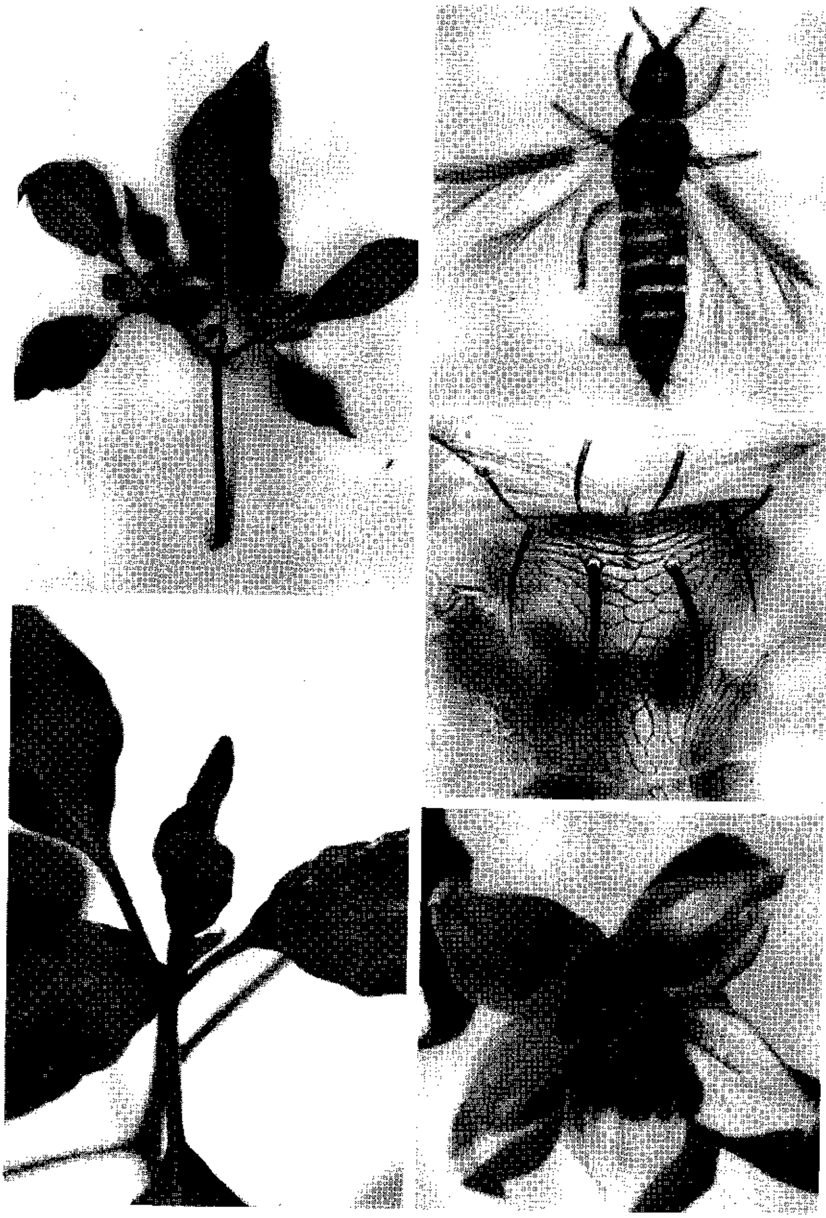

Figure 3.5. *Thrips parvispinus*. Above and below left: feeding injury symptoms on hot pepper. Above and centre right: ♀ (60x) and ♀ metanotum (700x), courtesy pictures G. Vierbergen (PD-DLO). Below right: thrips in hot pepper flower.

affected leaves initially show silvery, irregular blotches, due to mechanical feeding injury. After some time the silvery blotches turn light brown. Leaves curl upwards. During the daytime most thrips are hiding in hot pepper flowers. According to Kalshoven (1951) this thrips species pupates in soil. Among the other hosts of *T. parvispinus* are coffee, cucumber, *Datura* spp., tobacco and *Vigna* spp. (Jacot-Guillarmod, 1975). Sources of infestation are assumed to be susceptible crops and weeds, from where thrips migrate wind-borne.

There are several methods to assess *T. parvispinus* populations and injury levels. For population assessment studies, different techniques were tested. Coloured boards, made sticky with Thripstick® (active ingredient: polybutenes), were positioned vertically just above the crop canopy and examined after 24 hours. Routine use of such yellow and white sticky traps in five field trials repeatedly resulted in significantly ($P<0.05$) more thrips trapped on white than on yellow boards. This observation confirms results in Thailand by Lippold *et al.* (1975). However, two small-scale 1991 field experiments at different locations, comparing various coloured sticky boards, showed that light blue, 10 x 10 cm^2 sticky boards trapped significantly ($P<0.05$) more thrips than white, yellow, light green, dark green, orange and black boards. Small boards (10 x 10 cm^2) were more practical and gave equal or higher numbers of trapped thrips per dm^2 than equal surfaces in centres of larger boards (18 x 25 cm^2). Another, destructive method consisted of the picking of hot pepper flowers and immediately transferring these to bottles with alcohol or with water and detergent. After sieving the fluid containing flowers and thrips over filter paper, the number of thrips was counted. The method is only applicable during the flowering stage of the crop. Injury was assessed efficiently using a field key with a scale from 0 to 5 (Table 3.3).

Table 3.3. Field key to assess thrips injury in a hot pepper crop.

Score	Description*
0	No symptoms.
1	Less than 25 % of the plants have small silvery blotches on the lower sides of young leaves.
2	25 To 50 % of the plants have medium sized silvery blotches on the lower sides of young leaves.
3	50 To 75 % of the plants have medium sized silvery blotches on the lower sides of young leaves.
4	More than 75 % of the plants have large silvery blotches on most leaves.
5	All plants have large browning silvery blotches, together covering more than half of the leaf area on most leaves.

*Small blotches: < 3 mm diameter; Medium sized blotches: 3-5 mm diameter; Large blotches: > 5 mm diameter.

*Tropical army worm (*Spodoptera litura *Fabricius; Lepidoptera: Noctuidae) (Figure 3.6).* The larval stages of the tropical army worm are voracious leaf consumers. Pupation takes place in soil. After mating, female moths lay eggs in clusters on host plants. First instar larvae feed together, but late instar larvae feed solitary. Tropical armyworm has a wide host range among which banana, eggplant, maize, onion, papaya, potato, rice, soybean, tobacco, tomato, watermelon, and many others (Kranz *et al.*, 1977). The population build-up starts with the hatching of eggs deposited in clusters by actively flying female moths.

Field populations are monitored by counting numbers of egg clusters and/or feeding larvae per plant. Adult populations can be monitored by trapping moths in lure traps with sex pheromone (active ingredients: cis-9, trans-11 and cis-9, trans-12-tetradecadien-1-ol acetates) (Tamaki *et al.*, 1973). The injury assessment method, which consists of counting ratios of injured and non-injured leaves, is laborious and misleading when other leaf eating insects occur.

*Yellow tea mite (*Polyphagotarsonemus latus *Banks; Acari: Tarsonemidae) (Figure 3.7).* As thrips, the yellow tea mite especially affects young leaves. Leaves become rigid, develop a grey-brown shine on the lower sides of leaves and, in an advanced stage, react with curling downwards ('inverted spoon' symptom). Shoot growth is inhibited. Yellow tea mite is very polyphagous. Besides hot pepper it infests castor bean, citrus, cotton, jute, potato, rubber, sesame, tea, and other crops (Kranz *et al.*, 1977). Free-living *Tarsonemidae* are slow-moving or sedentary species (Krantz, 1978). Sources of infestation may be susceptible crops or weeds from where mites are passively dispersed by wind.

Yellow tea mite is too small to observe without the use of a hand lens. An accurate but time-consuming method to observe yellow tea mite populations is to sample leaves and to examine them by means of a binocular field microscope, counting numbers of mites. The count must be made immediately after sampling when the mites are still in position. Injury is assessed relatively rapidly by determining the percentage of plants with the typical 'inverted spoon' symptom.

Diseases

*Anthracnose fruit rot (*Colletotrichum capsici *(Sydow) Butler and Bisby,* C. acutatum *Simmonds ex Simmonds,* C. gloesporioides *(Penzig) Penzig & Saccardo; Fungi imperfecti: Melanconiales) (Figure 3.8).* The major symptom of anthracnose on hot pepper is the fruit rot. Green and ripe fruits can be affected. The rot starts as an indefinite, slightly sunken water-soaked spot. The rot enlarges and black pustules develop in concentric circles from the centre of the spot outwards. The anthracnose can extend to and infect the seed. *C. capsici* has a large host range, including tomato, and many others from a wide range of families (Mordue, 1971). *C. capsici* is seed-borne. It

Figure 3.6. Tropical army worm (*Spodoptera litura*). Above left: army worm egg-masses. Above right: army worm larva. Centre: feeding injury symptoms on hot pepper. Below left: army worm pupa. Below right: army worm moth.

Figure 3.7. Yellow tea mite (*Polyphagotarsonemus latus*). Above and below: Injury symptoms on hot pepper, 'inverted spoon' symptoms.

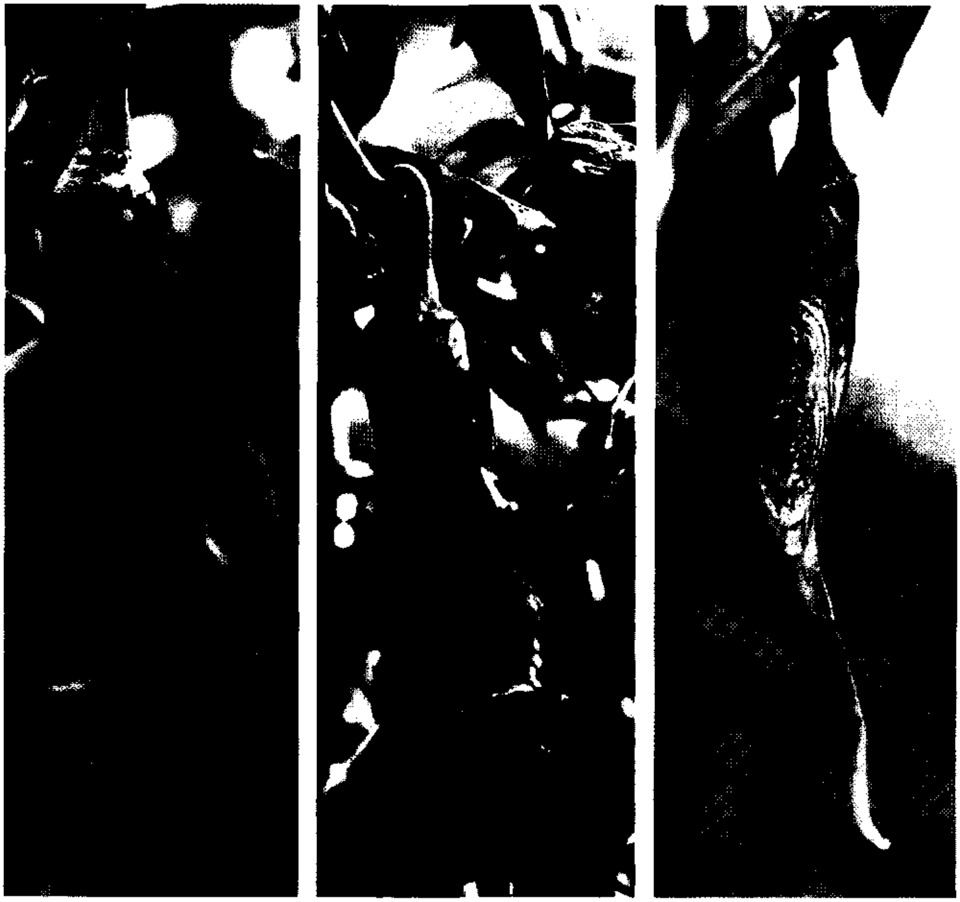

Figure 3.8. Anthracnose (*Colletotrichum capsici*). Left: rot on green hot pepper fruit. Centre: rot on red hot pepper fruit. Right: advanced stage of anthracnose fruit rot on hot pepper fruit.

persists in decayed fruits and other plant debris from which conidia are spread by water and wind. Although occurring during both wet and dry seasons, the disease is most serious during rainy periods.

Damage assessment consists of counting numbers of infected and healthy fruits at each harvest. The damage is expressed as the percentage of diseased fruits over all harvests.

*Bacterial wilt (*Pseudomonas solanacearum *(Smith) Smith; Schizomycetes) (Figure 3.9).* Bacterial wilt causes the wilting of adult plants. Initially, plants show partial wilting with afternoon recovery, but eventually the wilting is total and permanent. The vascular tissue of the main stem turns brown. Besides hot pepper, bacterial wilt affects a large number of hosts such as banana, eggplant, ginger, peanut, potato, tobacco, and tomato (Kelman, 1953). The bacterium is soil-borne, and can persist for many years. It invades the plant mainly through wounds in the root system. High soil temperatures (28-34 °C) and high soil moisture favour the disease.

Field observations, consisting of recording numbers of wilting plants, must be combined with confirmation of the causal agent as other reasons for wilting (mechanical injury, fungal wilt diseases) may occur. A simple and adequate test is to cut a piece from the stem base of a wilting plant and to place it in a glass container with clear water. When milky white fluid oozes out from the stem, bacterial wilt is present (Martin and French, 1985).

Cercospora *leaf spot (*Cercospora capsici *Heald and Wolf; Fungi imperfecti: Moniliales) (Figure 3.10).* Symptoms consist of circular or oblong spots ('frog-eyes'), especially on the leaves, but in case of a severe attack also on stems, petioles and peduncles. The spots have white to light grey centres and grey brown margins, and enlarge up to about 1 cm in diameter. In advanced stages of the disease, affected leaves turn yellow prematurely and drop off. According to Chupp (1953) the only host species of *Cercospora capsici* are *Capsicum annuum, C. baccatum* and *C. frutescens.* Analogous to *Cercospora beticola* on sugarbeet, it is supposed that the main source of infection is the soil, where the fungus can survive on crop residues, and that spores are spread by rain splash and wind (Canova, 1959).

Field observations consist of incidence and severity assessments. Disease incidence is assessed by counting plants with leaf spots. The progress of the disease severity in a field is monitored by use of a field key (Table 3.4).

Although usually present in the field at any time of the year, *Cercospora* leaf spot becomes more serious during rainy periods. Growth of the fungus in vitro is slow. On V-8 agar (Miller, 1955), optimum growth was obtained at 25 °C, with only 3.3 cm radial expansion of mycelium in 19 days.

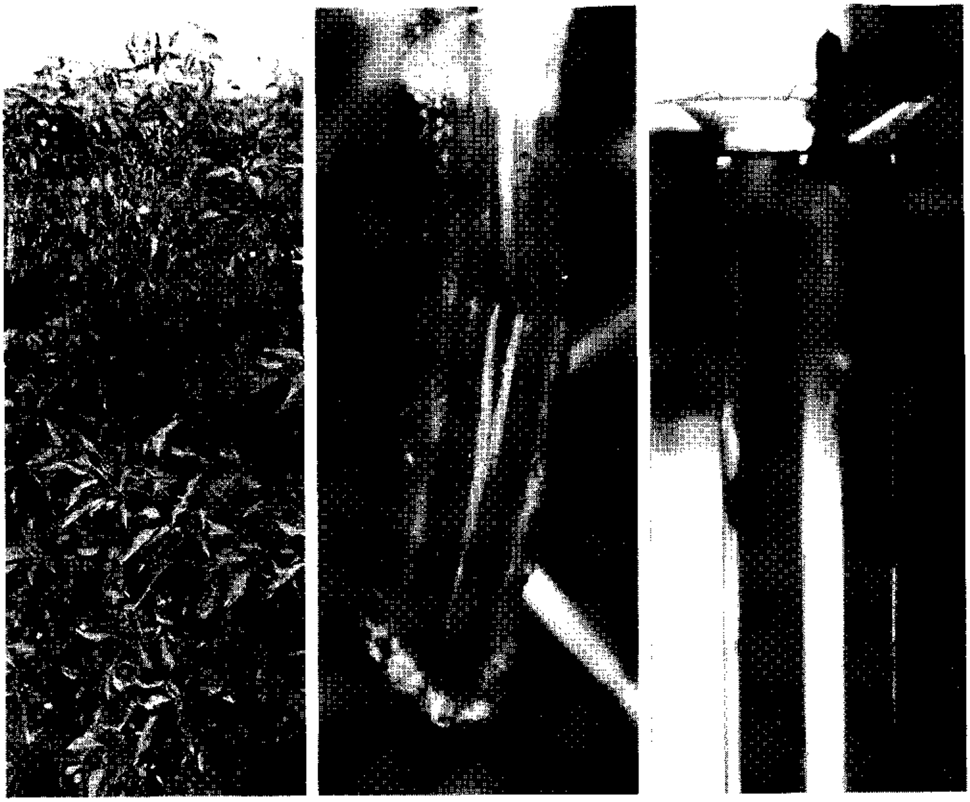

Figure 3.9. Bacterial wilt (*Pseudomonas solanacearum*). Left: wilting hot pepper plant. Centre: browning of vascular tissue of hot pepper stem base. Right: bacterial slime oozing out from a hot pepper stem cutting.

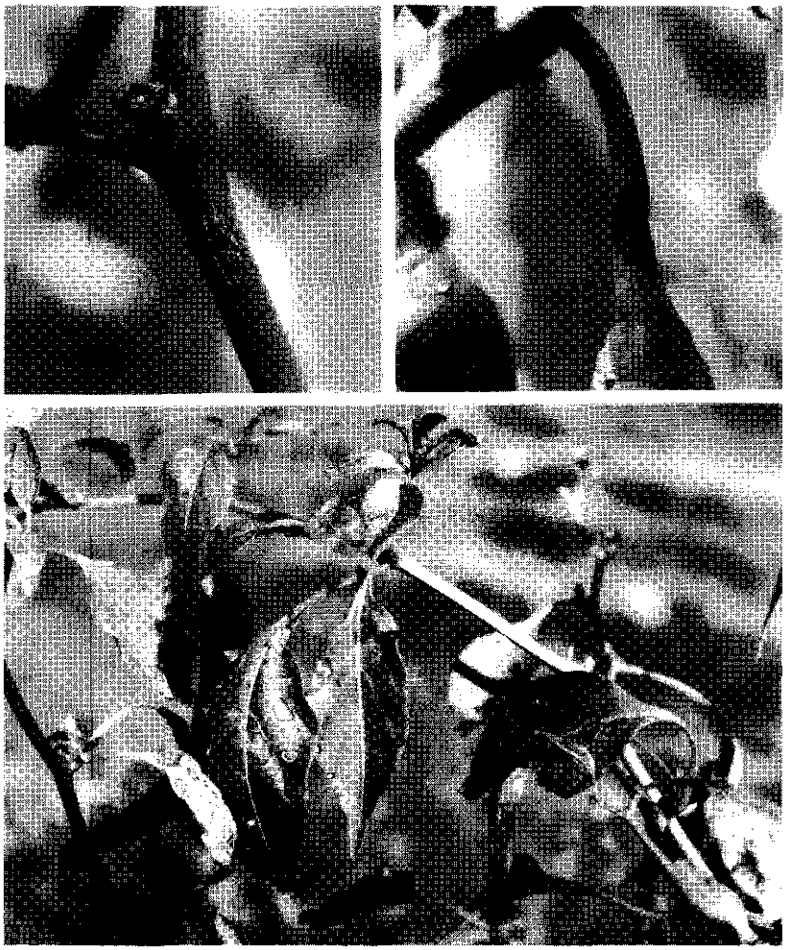

Figure 3.10. *Cercospora* leaf spot (*Cercospora capsici*). Above left: spot on hot pepper stem. Above right: spot on hot pepper peduncle. Below: spots on hot pepper foliage.

Table 3.4. Field key to assess *Cercospora* leaf spot injury in a hot pepper crop.

Score	Description
0	No symptoms.
1	Less than 50 % of the plants have 'frog-eye' spots on old leaves.
2	More than 50 % of the plants have spots on full-grown leaves.
3	All plants have spots on mature leaves, some affected leaves yellow.
4	All plants have spots on leaves of all ages, yellowed leaves drop off.
5	All plants have spots on leaves as well as on stems, petioles and/or peduncles; yellowing and defoliation of affected leaves is in an advanced stage.

*Southern blight (*Sclerotium rolfsii* Saccardo; Fungi imperfecti: Mycelia sterilia) (Figure 3.11).* Southern blight causes collar or stem rot of adult plants. The stem becomes infected at soil level. The affected stem is covered with white mycelium in which white sclerotia are formed that turn brown. Infected plants wilt and die. Other host plants are banana, bean, cabbage, cinchona, cucumber, peanut, potato, rice, sugar cane, tomato, and so on (Mordue, 1974). Transmission takes place through crop residues and weed hosts. The sclerotia may persist in soil for many years. They are spread by cultural practices, wind and water.

Natural infection in the field appears to be rather irregular. Field injury observations consist of monitoring percentages of infected wilting and dead plants.

Viruses (Figure 3.12). It is practically impossible to identify specific pepper viruses in the field based on symptomatology. Symptom expression is variable and often camouflaged, distorted or aggravated by other factors, such as thrips or mite feeding injury. Leaf symptoms include mosaic, vein banding, leaf curling, leaf narrowing and others. Fruits may malform and/or show mosaic before turning red. Infected plants often stunt and produce less fruits. At LEHRI, indirect ELISA resulted in the conclusion that potato virus Y (PVY), cucumber mosaic virus (CMV), tobacco etch virus (TEV), tobacco rattle virus (TRV), tobacco mosaic virus (TMV), tobacco ringspot virus (TRSV), potato virus X (PVX), potato virus M (PVM), tomato streak virus (TSV) and alfalfa mosaic virus (AMV) were present on hot pepper in Indonesia (Duriat, 1989). Dried leaf samples, sent to AVRDC in Taiwan and subjected to direct ELISA, resulted in another list of identified viruses: CMV, chili veinal mottle virus (CVMV), pepper mild mottle virus (PMMV), tomato mosaic virus (ToMV), PVY and PVX. CMV is a cucumovirus, which is isometric. CVMV, PVY and PTV are potyviruses and PVX is a potexvirus, all filamentous viruses. PMMV and ToMV are tobamoviruses, belonging to the group of rod-shaped viruses. Electron microscopic studies of virus containing leaf samples at IPO-DLO in the Netherlands only rarely revealed a few rod-shaped or filamentous particles (Figure 3.12).

Table 3.5 shows several discrepancies between identifications by two or three stations. In order to clarify some of these confusing results, 25 dried leaf samples were used to inoculate *Nicotiana occidentalis* accession P1 indicator plants at IPO-DLO in the

Figure 3.11. Southern blight (*Sclerotium rolfsii*). Above left and right: advancing stages of sclerotium formation around hot pepper stem. Below: wilting and dead plants due to southern blight.

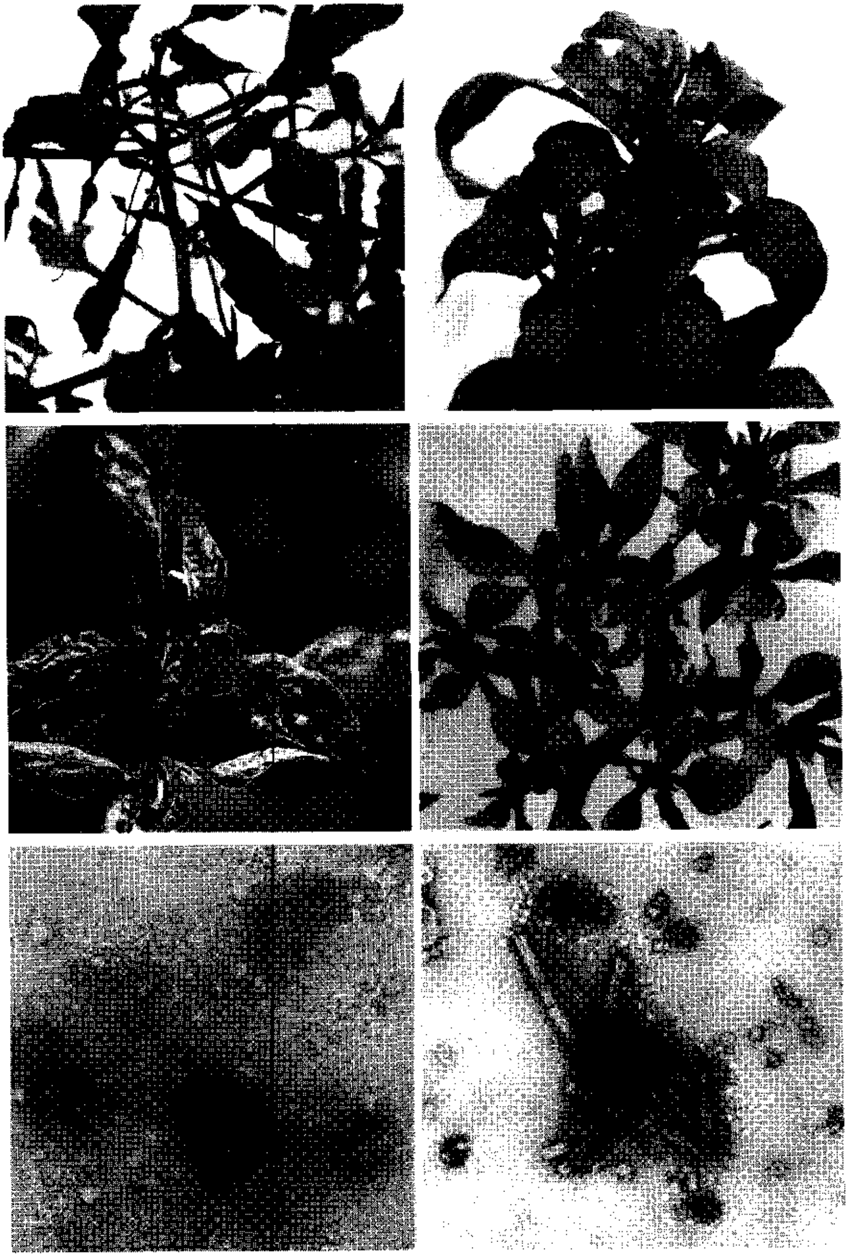

Figure 3.12. Viruses. Top four pictures: symptoms of suspected virus symptoms on hot pepper. Below left: electron microscopic picture of unidentified rod-shaped particles. Below right: electron microscopic picture of immuno-gold labelled CMV.

Table 3.5. Identifications of hot pepper leaf material with virus symptoms after drying: results of the indirect ELISA at LEHRI, direct ELISA at AVRDC and electron microscopic examinations at IPO-DLO.

Code	Location	Main symptom(s)	Identification results*		
			LEHRI	AVRDC	IPO-DLO
1	Subang	Mosaic	CMV, CVMV, TEV	CMV, CVMV	-
2	Subang	Mosaic	No viruses found	No viruses found	-
3	Subang	Blistering, mottling	CMV	CMV	-
4	Subang	Large chlorotic patterns	CMV	CMV	-
5	Subang	Blistering	TEV	CMV	-
6	Subang	Mosaic, filiform leaves	CVMV, ToMV, CMV, TEV	CVMV, CMV	-
7	Subang	Vein banding, filiform leaves	CMV, CVMV	CMV, CVMV	CMV, confirmed by inoculation of indicator plants.
8	Brebes	Mottling	CVMV	CMV	-
9	Brebes	Mottling	CVMV, AMV	CVMV, CMV	-
10	Brebes	Blistering	AMV	No viruses found	-
11	Brebes	Mosaic	CVMV?	CVMV	-
12	Brebes	Strong leaf curling	-	CMV	No viruses found.
13	Brebes	Strong leaf curling	-	CMV	Isometric virus particles?
14	Subang	Blistering	-	CVMV	No viruses found.
15	Subang	Vein banding	-	CVMV, CMV	No viruses found.
16	Subang	Blistering	-	CVMV	Few tobamovirus particles. ± 377 nm, no potyvirus.
17	Subang	Vein banding	-	CVMV, CMV	Few potyvirus, very few tobamovirus particles.

*Identification methods:
LEHRI: Indirect ELISA with CMV, ToMV, AMV, CVMV, TEV, PVY antisera.
AVRDC: Direct ELISA with CMV, ToMV, AMV, CVMV, TEV, PVY, PVX, TSWV antisera.
IPO-DLO: Electron microscopic examination, decoration with CMV, CVMV, PMMV antisera.
- = Not tested.

Netherlands. Three weeks after inoculation, CMV was detected in one indicator plant by use of the electron microscope decoration technique. This material was used to inoculate a *Chenopodium chinoa* indicator plant and a number of hot pepper seedlings. *C. chinoa* developed typical CMV local lesions symptoms. Symptom bearing hot pepper leaf material was next subjected to immuno-gold labelling at WAU. The results are illustrated by an electron microscopic picture with labelled CMV particles (Figure 3.12).

In the tropics, *Capsicum* spp. are natural hosts for at least 19 different viruses and most of these viruses infect a wide variety of tropical crops (Brunt *et al.*, 1990). CMV, PVY, CVMV and PTV are transmitted by aphids, while PMMV, ToMV and PVX are transmitted mechanically. PMMV and ToMV can be transmitted by seed (Green and Kim, 1991).

In the field, virus disease is assessed by incidence recordings. Percentages of plants with typical virus symptoms (mainly mosaic, vein banding, leaf narrowing) are recorded at regular intervals during a growing season. If possible, such observations should be confirmed by identification methods such as serological tests and/or inoculation of indicator plants.

Virus diseases occur at any time of the year, irrespective of the season. The earliness of infection with aphid-transmitted viruses is related to the aphid pressure in the field. Because of the major role of aphids in virus transmission, aphid (*Aphis gossypii* Glover) population assessment methods are mentioned. Aphid populations can be monitored by use of a yellow pan, filled with water, detergent and formalin (method after Moericke, 1955). In order to monitor aphids in relatively small field plots, vertical yellow sticky boards were used. These boards were positioned just above crop level and left in the field for 24 hours before examining them with a hand lense. Routine use of yellow and white 10x10 cm^2 traps in five field trials resulted in significantly ($P<0.05$) more aphids trapped on yellow than on white boards.

3.4 Natural enemies

Table 3.6 presents a brief and non-limitative list of natural enemies. The listed natural enemies were observed and collected in areas where pesticides were generally applied. Rearing of 53 oriental fruit fly larvae collected in Subang resulted in 40 adult oriental fruit flies and 13 adult parasitoids (Opiinae: *Psyttalia* spp.). Solitary wasps (*Sphex ambrosius*) and dragonflies (Odonata) were often seen to attack small grasshoppers on hot pepper plants. *Oxyopes lineatipes* was observed to attack *Hypomeces squamosus* (Figure 3.13). *Coccinella repanda* Thunberg fed on aphids.

Table 3.6. Some natural enemies of hot pepper arthropod phytophages, encountered at low elevations on Java, Indonesia.

Common name	Scientific name	Observed prey(s)	Confirmation by
-	*Oxyopes lineatipes* Koch	*Hypomeces squamosus*	Vierbergen/Van Helsdingen, PD 1993
-	Opiinae (*Psyttalia* spp.)	*Bactrocera dorsalis*	Van Achterberg, NNM 1994*
-	*Paederus fuscipes* Curtis	Thrips (?)	Van Vreden, LEHRI 1991
Dragon flies	Odonata	Grasshoppers	-
Transverse ladybird	*Coccinella repanda* Thunberg	Aphids	De Goffau, PD 1993
Solitary wasp	*Sphex ambrosius* CHR	Grasshoppers	Van Vreden, LEHRI 1991

*NNM = National Nature historic Museum, Leiden, the Netherlands.

Table 3.7. A phenological scale for hot pepper under tropical low elevation (below 200 m asl) conditions on Java, Indonesia.

Location	Developmental stage		Growth stage Code	Description	Number of days* Average	Range
Nursery	Vegetative		1	Sowing to emergence	9	6 - 12
			2	Emergence to transplanting	23	20 - 26
Field			3	Transplanting to first plant flowering	20	12 - 26
	Generative:	Flowering &	4	0 To 50 % of plants flowering	16	7 - 32
		Fruiting	5	50 % Of plants flowering to 50 % fruiting	5	3 - 23
			6	50 % Fruiting to first harvest	24	14 - 30
		Harvesting	7	First harvest to 50 % of fruits harvested	31	7 - 70
			8	50 % Harvested to last harvest	22	5 - 37
Total growth period					150	121 - 180

*Based on 11 field trials in LEHRI experimental stations.

Figure 3.13. Spider (*Oxyopes lineatipes*) attacking green snout beetle (*Hypomeces squamosus*).

3.5 Phenology of hot pepper and its phytophages

Table 3.7 gives a phenological scale of eight growth stages for hot pepper, with the approximate duration of each stage. The table is based on 11 field trials conducted under low elevation conditions, in different localities and seasons.

The occurrence of and injury by phytophagous organisms depends on crop development and on environmental conditions. Hence, not all species of harmful agents simultaneously attack a crop. Phytophage incidences were derived from field observations in trials and production areas. Although seasonality may play an important role in their epidemiology, major phytophages can cause problems throughout the year due to farmers' practices, such as irrigation during dry seasons. For this reason, observations from dry and wet season trials on crop development and phytophages were combined. Figure 3.14 shows that cotton jassid, thrips, tropical army worm, viruses and yellow tea mite may begin to cause injury during the vegetative stages already. Another leaf injuring agent, *Cercospora* leaf spot, has an initially slow epidemic build-up, and is most harmful during and after fruit set. Bacterial wilt and southern blight generally cause symptoms during the fruiting and harvesting stages. The fruit injuring diseases and pests, anthracnose fruit rot, cotton boll worm and oriental fruit fly only harm the fruiting and harvesting stages.

3.6 Discussion and conclusions

Data on identification and diagnostics of hot pepper pests and diseases in Indonesia were published during the first half of the 20th century. The observations by Kalshoven (1951) are still valuable and many of his descriptions of arthropod pests on hot pepper are confirmed in this paper. Since Kalshoven's publication, much attention was given to chemical control, resulting in numerous publications on pesticide screening experiments. At present, hot pepper farmers in a number of major production areas on Java apply chemical control as the main method to combat crop health problems (Chapter 2). Ecological factors that influence epidemics of single phytophages only lately received more attention, possibly as a result of the spread of the integrated pest management (IPM) theory. Researchers are tempted, or even obliged, to concentrate on the study of one harmful species at a time. If so, their recommendations need not result in improved crop health as other phytophages occur simultaneously and, at times, take over. For this reason the concept of integrated crop management (ICM) is promoted (Chapter 1), which implies that major attention should be given to a healthy crop and its environment, and not just to single injurious phytophages.

There are contradictions between the list of hot pepper pests and diseases in this paper and the lists published elsewhere. The list of Dammerman (1919) mentions many other

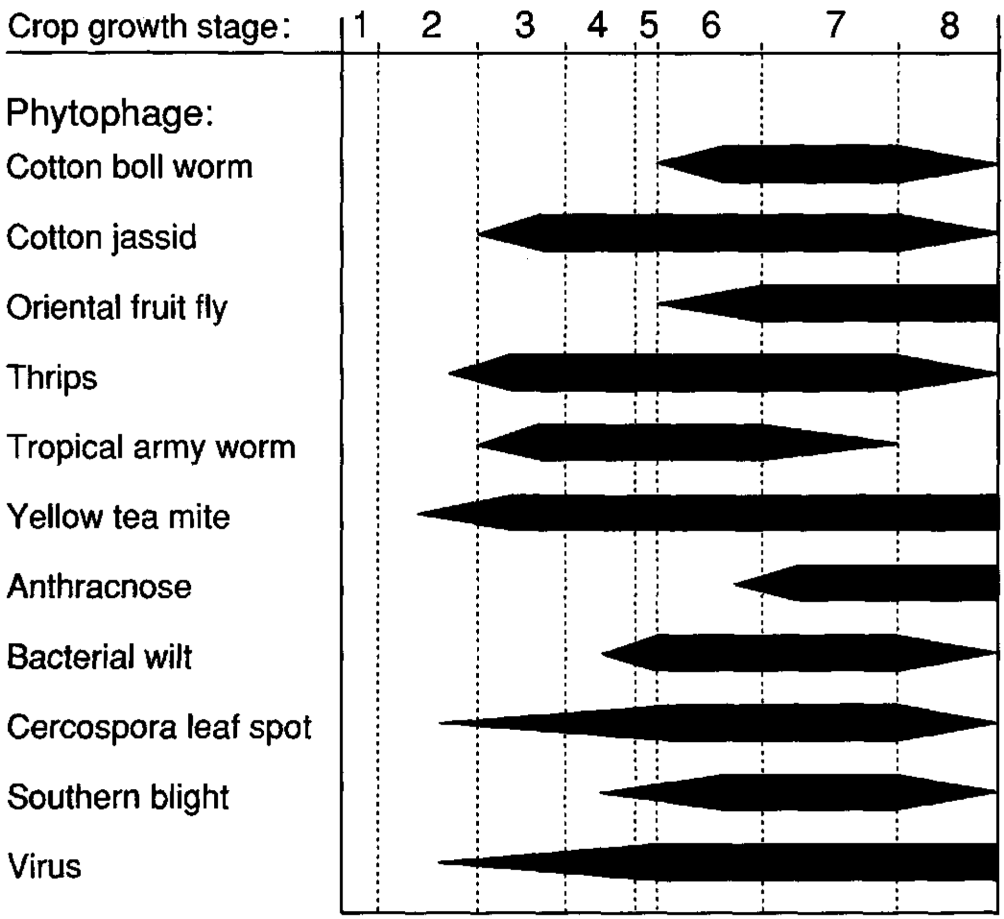

Figure 3.14. Schematic presentation of the occurrence of injury by major hot pepper phytophages under tropical low elevation conditions in Java, Indonesia. Bars indicate the crop stages that are vulnerable to different phytophagous species.

pest species attacking solanaceous crops, but these could have been observed on crops other than hot pepper, such as eggplant, potato or tomato. Semangun (1989) for instance mentioned *Phytophthora* spp. as a major cause of disease in hot pepper. This fungus indeed affects hot pepper in high elevation areas but not at low elevations. The discrepancy between the various identifications of hot pepper viruses in Indonesia has not yet been clarified. Some of the serological identifications could not be confirmed by the authors.

In other countries of Southeast Asia, major problems with crop health of hot pepper appear to resemble those in Indonesia. In Malaysia major problems are imposed by oriental fruit fly, cotton boll worm, virus, bacterial wilt, anthracnose, *Cercospora* leaf spot, southern blight and *Choanephora* spp. (Shukor *et al.*, 1989). A questionnaire survey by AVRDC revealed that in tropical Asia major hot pepper diseases are caused by viruses, *Phytophthora* spp., anthracnose and bacterial wilt (Yoon *et al.*, 1989).

Under humid tropical low elevation conditions, temperature and relative humidity do not fluctuate drastically and crops are grown throughout the year. The 11 major hot pepper phytophages described here are polyphagous, *Cercospora capsici* excepted. It is assumed that the polyphagous phytophage populations survive on other crops or on weeds during periods free from hot pepper crops. Epidemics on hot pepper will develop under conditions favourable to the pathosystem, for instance dry periods for thrips and rainy periods for anthracnose. Multiple infection and injury by more than one phytophage are considered the rule rather than the exception. Interactions between different phytophages are likely to exist, but are not yet adequately described. It is supposed that for instance plant-pathogenic nematodes cause an increase in the incidence of bacterial wilt. Such interactions on hot pepper have not yet been investigated, but should be considered when crop protection programmes are formulated. Crop health should be given the major attention and crop management practices should be tuned to the expected build-up of epidemics as projected in Figure 3.14.

Chapter 4

Plant raising techniques as components of integrated crop management of hot pepper (*Capsicum* spp.) under tropical lowland conditions

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Submitted.

Abstract: As a potential contribution to integrated crop management (ICM) of hot pepper in tropical lowlands, effects of different plant raising techniques were investigated. The techniques studied included covering the nursery, raising transplants in pots and varying the duration of the nursery period. Crop performance was measured by variables such as emerged seedlings, leaves per transplant, crop establishment after transplanting, plant height and fruiting. Crop health was monitored by following the development of pests and diseases, such as thrips, yellow tea mite, anthracnose fruit rot, blossom mould, *Cercospora* leaf spot, southern blight and aphid-transmitted viruses. Crop production was measured as yield of healthy fruits, mean weight per healthy fruit and earliness of harvesting. Potted transplants showed better crop establishment and earlier harvesting after transplanting than bare-root transplants. A nursery period of 1½ months appeared optimal for plant growth and earliness of harvesting. Screen-covered nurseries protected plants from aphids and aphid-transmitted viruses during the nursery phase, and improved fruiting and crop production after transplanting. Use of screen-covered nurseries should make application of pesticides during the plant raising phase superfluous. Raising plants in pots under a screen cover during 1½ months was proposed as an element of ICM. Healthy and vigorous transplants yielded better only when other elements of ICM were included during the field phase of the crop cultivation.

4.1 Introduction

Research on integrated crop management (ICM) was initiated to alleviate hot pepper (*Capsicum* spp.) crop health problems and to enhance production in low elevation areas in Indonesia (Chapter 1). ICM concentrates on reducing the vulnerability of a crop by improving growth and development, in addition to protecting the crop against pests and diseases. The raising of vigorous and healthy plant material is an essential element of ICM.

Exploratory surveys to major low elevation hot pepper production areas in Java revealed the plant raising methods of farmers (Chapter 2). Farmers generally produce seed from their own field. After processing, the seed is stored on a dry site at ambient temperature. The next season, farmers broadcast the seed in a seed bed of soil mixed with stable manure. To protect the germinating seeds from direct sunlight and dehydration, the seed bed is covered with rice straw or other plant material for seven to ten days after sowing. Sometimes a temporary roof of plant material is constructed above the seed bed. Most farmers apply fertilizers (mainly urea) and pesticides (mainly insecticides) during the nursery period. After 4½ to 11 weeks in the nursery, the plantlets are lifted and transferred to the field as bare-root transplants.

The farmers' plant raising methods are assumed to negatively affect crop performance and crop health. The germination capacity may be low when storage conditions are improper, and the farmers' seed may be infected by *Colletotrichum* spp. (causing anthracnose), tomato mosaic virus (ToMV) or other pathogens (Belletti and Quagliotti, 1988; Green and Kim, 1991; Hadden and Black, 1988). In open, non-covered nurseries, seedlings are exposed to aphids that vector viruses, such as cucumber mosaic virus (CMV) and chili veinal mottle virus (CVMV), which are the most important hot pepper viruses on Java, Indonesia (Chapter 3). Handling of bare-root plantlets at transplanting causes root damage, inducing prolonged recovery periods in the field and increased vulnerability to soil-borne pests and diseases.

Coons *et al.* (1989) found maximum rates and percentages of germination of both sweet and hot pepper seeds at constant temperatures of 25 to 30 °C. Poor germination occurred at temperatures between 35 and 40 °C, but proper germination was possible at alternating temperatures such as 40/25 °C (12 h at each temperature). Bradford *et al.* (1990) found that sweet and hot pepper seed priming with KNO_3 shortened the mean time to seedling emergence, especially in case of slowly germinating seed lots.

Protected raising of vegetable seedlings in aphid-proof, screen-covered nurseries is expected to result in virus-free plantlets, provided that virus-free seed is available. To prevent entrance of mites, screen should have a mesh $\leq$ 63 μm, to prevent thrips $\leq$ 130 μm, and to prevent aphids $\leq$ 400 μm (Ramakers, 1990).

Weston (1988) found that sweet pepper transplants in bigger pots (volume 40 versus 31, 25, 19, 6 cm^3) and grown during longer nursery periods (60 versus 30, 40, 50 days) had a higher early yield, although total yield was not affected. Leskovar *et al.* (1990) compared sweet pepper plants, directly seeded in the field, with transplants, raised in pots in a nursery, and found that transplants exhibited a faster initial root growth and an increased fruit growth and production.

This study was undertaken to investigate transplant raising methods in order to improve the quality of planting material and to improve crop health during and after the nursery phase. Effects of several plant raising methods on crop performance, health and production are described.

4.2 Materials and methods

Experimental sites

Field trials were conducted at the low elevation experimental sites of the Lembang Horticultural Research Institute (LEHRI) in Brebes (Central Java, 10 m above sea level) and Subang (West Java, 110 m above sea level) in Indonesia and of the Malaysian Agricultural Research and Development Institute (MARDI) at Klang (Selangor Darul Ehsan, 3 m above sea level) in Malaysia. In the Brebes wetland area, vegetables are produced during the dry season, using the system of cambered beds and furrows (Ind: *surjan*). LEHRI Subang represents dryland vegetable areas with vegetable production mainly during the rainy season. MARDI Klang represents peat soil areas with continuous vegetable production. In Brebes the soil is a fluvisol with a pH-H_2O of 7, in Subang an acrisol/nitisol with pH-H_2O 5, in Klang a histosol with pH-H_2O 4. Table 4.1

gives an overview of the weather conditions during seven field trials.

Table 4.1. Overview of weather conditions during seven hot pepper plant raising trials, indicating location, period, and averages of temperature, relative humidity, monthly rainfall and yield of healthy fruits.

Trial	Location	Period	Temperature (°C) Min	Max	RH (%) Min	Max	Rainfall (mm)	Yield (t/ha)
A.	Brebes	Aug'89-Jan'90	23	33	66	96	175	5.4
E.	Subang	Aug'90-Jan'91	20	37	55	96	192*	5.3
H.	Subang	Mar'91-Jul'91	22	36	52	98	83*	-
J.	Subang	Nov'91-Apr'92	22	37	54	96	357	-
O.	Klang	May'93-Dec'93	23	33	58	97	191	11.3
Q.	Klang	Aug'93-Jan'94	23	33	60	98	255	5.3
R.	Klang	Sep'93-Mar'94	23	33	57	97	272	2.3

*Possibly over- or underestimated due to temporary failure of equipment.

\- = Missing data.

Description of trials

Experimental designs, factors and treatments of the conducted trials are listed in Table 4.2. During the field phase of the Trials A, E, H, J and O, no experimental factors were added. In the Trials Q and R, the factors mulch (bare-soil against silvery plastic mulched) plus nitrogen (200 against 300 kg N/ha) and mulch were added in the field, respectively. Table 4.3 shows an overview of cultural methods applied in each trial. During the nursery and field phases, irrigation and weeding were conducted when necessary. Fertilization was according to LEHRI and MARDI recommendations, respectively. Trial E, representing the Trials A, E, H and J in Indonesia, and Trial O, representing the Trials O, Q and R in Malaysia, are described in detail.

The hot pepper seed material in Trial E was 'Tit Paris-LV 2699', a relatively homogeneous selection of a popular landrace from Brebes. Nursery roofs were constructed of bamboo frames (circa 1 m high), on top covered with transparent plastic or palm leaves. The open, 'no cover' nurseries consisted of uncovered bamboo frames. Screen-covered nurseries consisted of bamboo tunnels (½ m high) covered with screen. Two types of screen were tested, with a mesh of 560 and 240 μm. To minimize the risk of introducing soil-borne diseases, the soil medium was made up of sub-soil, mixed with compost. The granular insecticide carbofuran (10 g/m^2) was applied to the seed bed. The seeds were treated with the fungicide propamocarb hydrochloride (2 ml/l). Some 200 seeds per plot were broadcasted. Seed beds were covered with banana leaves to keep soil humidity high, until about one week after sowing. After emergence, seedlings were transferred to banana leaf pots (φ 4 cm), except for the non-potted treatment. Four days before transplanting, nursery covers were removed to harden the plants. Five

Table 4.2. Experimental design of seven hot pepper nursery trials with various experimental factors and treatments during the plant raising phase.

Trial	Design*	Replicates	Factors	Treatments
A.	SP	2	Cover	No cover
				Transparent plastic roof
				Sugar-cane leaves roof
			Seed bed	No pots
				Seed box (80x50x10 cm)
				Banana leaf pots (4 cm ϕ)
				Plastic bags (8 cm ϕ)
E.	SP	4	Cover	No cover
				Transparent plastic roof
				Palm leaves roof
				Screen cover (mesh 560 μm)
				Screen cover (mesh 240 μm)
			Seed bed	No pots
				Banana-leaf pots (4 cm ϕ)
				Plastic bags (8 cm ϕ)
H.	SSP	3	Cover	No cover
				Transparent plastic roof
				Screen cover (mesh 560 μm)
			Seed bed	No pots
				Banana-leaf pots (4 cm ϕ)
			Period	30 days
				45 days
				60 days
J.	SSP	4	Cover	No cover
				Screen cover (mesh 560 μm)
			Seed bed	No pots
				Plastic bags (8 cm ϕ)
			Period	30 days
				45 days
				60 days
O.	SP	5	Cover	No cover
				Screen cover (mesh 600 μm)
			Period	30 days
				44 days
				58 days
Q.	RCB	5	Cover	No cover
				Screen cover (mesh 600 μm)
R.	RCB	5	Cover	No cover
				Screen cover (mesh 600 μm)

*SP = Split-Plot; SSP = Split-Split-Plot; RCB = Randomized Complete Block.

weeks after sowing, the plantlets were transplanted. The banana leaf pots were not removed at transplanting. The field was designed as a randomized complete block in four replications. From each nursery treatment, plantlets were transferred to correspondingly coded field plots. Plot size was 6 m^2, with 20 plants per plot and a planting distance of 50 x 60 cm. Rice straw was used as a mulch. Pesticides were

Table 4.3. Cultural techniques, applied in seven hot pepper plant raising trials, during nursery and field phases, among which cultivar choice, seed treatment before sowing, number of seeds sown per plot in the nursery, duration of the nursery period (days), number of plants per plot after transplanting in the field, plot size in the field (m^2), use of mulch in the field, number of chemical pesticides applications during the field phase.

Trial	Cultivar	Seed treatment	# Seeds per plot	Nursery period (days)	# Plants per plot	Plot size (m^2)	Mulch	Chemical pesticides
A.	Tit Paris	Luke-warm water	250	34	60	4.5*1.4	Rice straw	14 * Fungicide 19 * Insecticide
E.	Tit Paris	Propamocarb-hydrochloride	200	33	20	5.0*1.2	Rice straw	23 * Fungicide 23 * Insecticide
H.	Tit Paris	Propamocarb-hydrochloride	100	30/45/60	24	3.0*2.4	Rice straw	N.a.
J.	Tit Paris	Propamocarb-hydrochloride	200	30/45/60	24	3.0*2.4	Rice straw	N.a.
O.	MC4	-	200	30/44/58	60	6.0*6.0	Silvery plastic	6 * Acaricide
Q.	MC4	-	200	44	60	6.0*6.0	No mulch/ Silvery plastic	5 * Acaricide 3 * Fungicide
R.	MC4	-	200	47	60	6.0*6.0	No mulch/ Silvery plastic	5 * Acaricide 5 * Fungicide

N.a. = Not applicable (field phase was terminated prematurely).
- = Not applied.

applied according to a local spray schedule, adding up to 23 fungicide (mancozeb or maneb) and 23 insecticide (dimethoate or profenofos) applications.

In Trial O the MARDI cultivar 'MC4' was used. Nurseries were made up of wooden frames (1 m high), that were closed off with chicken wire to keep rats away ('no cover' treatment), or with screen (mesh 600 μm; 'screen cover' treatment). The soil mixture consisted of sub-soil, sand and manure. Carbofuran (5 g/m^2) was applied to the seed bed. Some 200 untreated seeds were sown per plot per nursery period, for three consecutive sowing dates with 14 days intervals. Seeds were sown in polystyrene foam 'speedling trays' and emerged seedlings were transferred three weeks after sowing to plastic bags (ϕ 6½ cm). Five days before transplanting, nursery covers were removed to harden the plants. Transplanting was done on the same day in all plots, at 1, 1½ and 2 months after sowing, respectively, according to the planned nursery periods. The plastic bags were removed at transplanting. The field was laid out as a split-plot in five replications. From each nursery treatment, plantlets were transferred to correspondingly coded field plots. Plot size was 36 m^2, with 60 plants per plot and a planting distance of 60 x 100 cm. Silvery plastic was applied as a mulch. Pesticide applications were restricted to two applications with a fungicide (copper hydroxide), one with an insecticide (carbofuran plant hole application before transplanting), six with an acaricide (dicofol) and eight with the biological control agent *Bacillus thuringiensis.*

Observations

In Table 4.4, the responses are listed, that were observed during nursery and field phases of all trials.

Nursery conditions. The light transmission in nurseries in Indonesia was recorded with a light-intensity meter (400 - 700 nm). The light intensity was measured both at canopy level and above the nursery cover, and the proportion received at canopy level was assessed. In Malaysia, the light transmission was assessed with a lux meter by measuring both inside and outside the nursery at ground level and calculating the proportion received inside. Soil temperature at 10 cm depth was measured at noon using a digital thermometer. The minimum and maximum relative humidity and air temperature at circa ½ m above ground level were recorded with thermohygrographs.

Crop performance. At transplanting, the proportion of raised plantlets per plot was assessed as the number of plantlets divided by the number of seeds sown. The plantlet height or the number of leaves per plantlet was assessed at transplanting on 10 plantlets per plot. Until 14 days after transplanting, crop establishment was determined as the complement of the number of replacements of dead transplants, divided by the total number of plants, per plot. Crop growth in the field was monitored by measuring the average plant height of 10 marked plants per plot every 2 weeks. Crop development was observed by weekly counts of the proportion of plants with at least one fruit of more than 1 cm length.

Table 4.4. Responses of hot pepper crop performance and crop health, observed during nursery and field phases of seven plant raising trials.

Trial	Nursery phase		Field phase	
	Performance	Health	Performance	Health
A.	Plantlet height # Plantlets	-	Establishment Fruiting Plant height	-
E.	Plantlet height # Plantlets	-	Establishment Fruiting Plant height	Viruses
H.	# Plantlets	Thrips Viruses	Establishment	-
J.	Plantlet height # Plantlets	Viruses	Establishment Fruiting	-
O.	# Leaves # Plantlets	Aphids Viruses	Establishment Fruiting Plant height	Anthracnose fruit rot *Cercospora* leaf spot Yellow tea mite Southern blight Thrips Viruses
Q.	-	Aphids Viruses	Establishment Fruiting Plant height	Anthracnose fruit rot Blossom mould *Cercospora* leaf spot Yellow tea mite Thrips Viruses
R.	# Leaves # Plantlets	Aphids Viruses	Establishment Fruiting Plant height	Anthracnose fruit rot Blossom mould *Cercospora* leaf spot Yellow tea mite Viruses

- = Not observed.

Crop health. Two-sided yellow sticky traps (25x25 cm) were positioned in the nurseries at circa ½ m above ground level and renewed weekly to observe the number of aphids trapped. Before transplanting, the incidence of viruses (mainly CMV and CVMV) and thrips (*Thrips parvispinus* Karny) was recorded as the number of plantlets showing symptoms of virus infection or thrips infestation, respectively, divided by the total number of plantlets, per plot. After transplanting, weekly incidence observations were performed on blossom mould (*Choanephora cucurbitarum* (Berkeley & Ravenel) Thaxter), *Cercospora* leaf spot (*Cercospora capsici* Heald & Wolf), yellow tea mite

(*Polyphagotarsonemus latus* Banks), southern blight (*Sclerotium rolfsii* Saccardo), thrips and viruses by observing the number of plants with symptoms, divided by the total number of plants, per plot. In the case of blossom mould, diseased twigs were removed when incidence was determined, as a means of sanitation. The loss of fruits due to anthracnose fruit rot (*Colletotrichum* spp.) was expressed as the number of infected fruits accumulated over successive harvests divided by the total number of harvested fruits, per plot. Symptoms of *Cercospora* leaf spot, southern blight, thrips, yellow tea mite, and viruses on hot pepper were described in Chapter 3.

Crop production. For the present purpose, total (accumulated) yield in kg per ha is not relevant. "Healthy yield" is defined as the yield of healthy fruits expressed in t/ha. Healthy yield was recorded as the weight of ripe, healthy fruits accumulated over all harvests, per plot. The mean weight per healthy fruit was calculated as the healthy yield divided by the number of healthy fruits, per plot. The earliness of harvesting was expressed as the mid-harvest time, the day at which half of the total yield of healthy fruits was attained.

Statistical procedures

The results of the successive observations on plant height and proportion of fruiting plants per plot in the field were used to calculate second degree polynomials ($Y = a + b*X + c*X^2$; X = time in days after transplanting) using multiple regression on time. The mid-fruiting time was calculated ($X_{Y=0.5}$) as the day at which half of the plants had set fruit. The sequential data on blossom mould and *Cercospora* leaf spot were used to calculate the Area Under the Disease Progress Curve (AUDPC), per disease and per plot. AUDPC is the disease intensity integrated over time between two observation dates, and expressed in 'proportion-days', using the trapezoidal integration method (Campbell and Madden, 1990). The successive data on yellow tea mite and thrips were processed by the same method (Area Under the Pest Progress Curve (AUPPC)). The virus observations were transformed into logits ($Y'=\ln[Y/(1-Y)]$; Y = proportion of plants diseased). Per plot, sequential logit values were subjected to linear regression on time to describe the progress of the natural epidemic (Van der Plank, 1963). Virus mid-value time ($X_{Y=0.5}$) was calculated as the day at which half of the plants showed virus symptoms, per plot. The data on dead plants due to southern blight were accumulated per plot.

All numerical results per plot, the AUDPC and AUPPC values, regression parameters and mid-value times were analyzed using Analysis Of Variance (ANOVA). Whenever significant differences were found ($P<0.05$), treatment means were separated using the Least Significant Difference (LSD) test.

4.3 Results

Nursery conditions

The data on light transmission, soil temperature, relative humidity and air temperature are summarized in Table 4.5. Light transmission and soil temperature were reduced significantly in covered nurseries. The maximum air temperature was reduced and the RH increased in screen-covered nurseries, but data on air temperature and RH were not analyzed statistically.

Table 4.5. Environmental conditions in various nursery treatments of three plant raising trials, indicating light transmission at crop level, soil temperature at 10 cm depth, air temperature (min/max) and relative humidity (min/max). Separation of means by LSD ($P<0.05$).

Observation	Light transmission (%)	Temperature (°C)		R.H. (%)
		Soil	Air	
Trial	E.	H.	J.	J.
No cover	96 a	31.3 a	22/40	44/95
Transparent plastic roof	62 b	30.4 b	-	-
Palm leaves roof	16 d	-	-	-
Screen cover*	56 bc	29.6 c	23/36	50/100
$LSD_{0.05}$	11	0.1	-	-

- = Not measured.

*Mesh 560 µm.

Crop performance

In all trials, the proportion of seeds developing into vigorous plantlets was lowest in non-covered nurseries. The seed box treatment in Trial A was abandoned, due to poor emergence.

Plantlets raised in a covered nursery were taller or had developed more leaves at transplanting than those raised in a non-covered nursery (Figure 4.1). In Trial J, nursery periods of 1, 1½ and 2 months resulted in plantlets of increasing height, namely 7, 21 and 36 cm, respectively ($LSD_{0.05}$=4), and in Trial O in plantlets with increasing numbers of leaves, namely 5, 10 and 17, respectively ($LSD_{0.05}$=1). Throughout the growing period in the field, plants originating from non-covered nurseries generally remained shorter than the others. In Trial Q, the plant height growth rate, parameter b of the second-degree polynomial, was influenced by nursery covers, as transplants from screen-covered nurseries grew significantly faster than transplants from non-covered nurseries. In Trial O, 1½ months old plantlets grew significantly faster after transplanting than either the 1 or 2 months old plantlets (Figure 4.2).

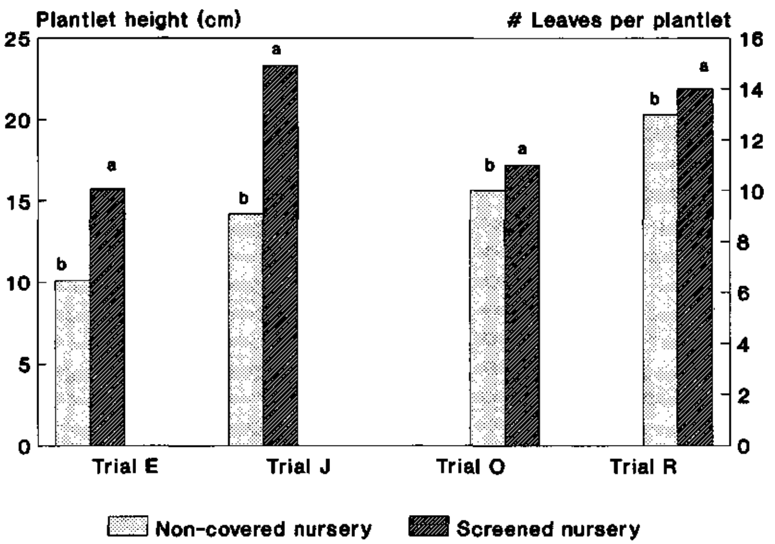

Figure 4.1. Hot pepper plantlet height (Trials E, J) and number of leaves (Trials O, R) in non-covered and screen-covered nurseries at transplanting time, in plant raising trials. Seperation of means by LSD ($P<0.05$).

In Trials E and H, the establishment of transplants in the field from non-covered nurseries was significantly worse than from covered nurseries, but in other trials no significant differences were obtained. In Trials A and E, significantly better crop establishment of potted transplants was observed, compared to bare-root transplants. In Trials H, J and O, the 1 month nursery period caused significantly worse crop establishment than the 1½ or 2 months nursery periods.

In Trials E, J, Q and R, mid-fruiting times were significantly shorter for transplants from covered nurseries than from non-covered nurseries. The longer the nursery period, the shorter the mid-fruiting time in the field in Trials H, J and O. In Trial O, the mid-fruiting time was 48 days after transplanting in the 1 month raising treatment, significantly longer than the 37 and 35 days respectively in the 1½ and 2 months raising treatments ($LSD_{0.05}$ = 5). Potted transplants had a significantly shorter mid-fruiting time than bare-root transplants in Trials A and E.

Crop health

Nursery. In Trial H the proportion of plantlets with thrips damage was significantly lower in screen-covered than in non-covered nurseries (Table 4.6). In Trials O and Q, no thrips injury had been observed during the nursery period, and thrips incidence in the field

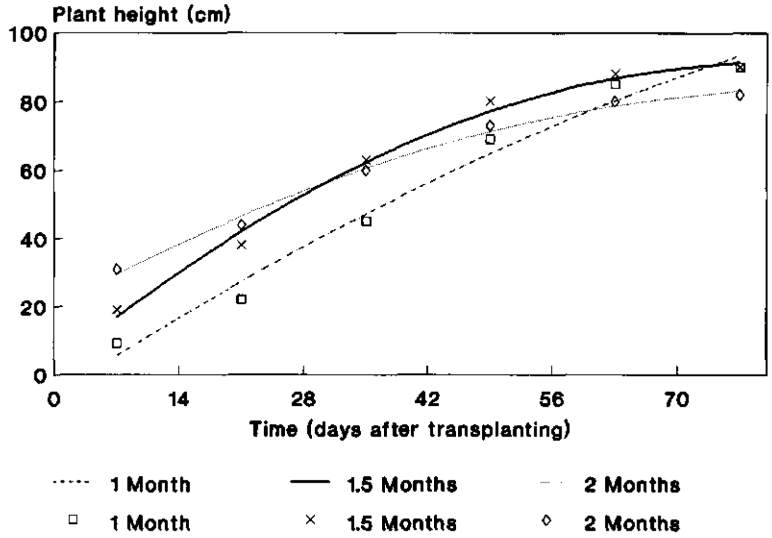

Figure 4.2. Observed values and regression curves of hot pepper plant height in the field, of transplants, that had been raised during nursery periods of 1, 1½ or 2 months, in plant raising Trial O (Y = Plant height in cm; X = Time in days after transplanting).

Y_{1month} = -6.3 + 1.73*X - 0.006*X^2 (r^2 = 0.97)

$Y_{1½month}$ = 2.3 + 2.19*X - 0.013*X^2 (r^2 = 0.96)

$Y_{2months}$ = 19.8 + 1.45*X - 0.008*X^2 (r^2 = 0.84)

showed no influence of nursery covers.

The number of aphids on sticky yellow traps was significantly lower in screen-covered than in non-covered nurseries in Trials O, Q and R, the largest difference being 3 against 56 aphids per nursery throughout the nursery period (Table 4.6).

Table 4.6. Proportion of plantlets injured by thrips at transplanting in various nurseries in plant raising Trial H, and accumulated numbers of aphids trapped on, weekly observed, yellow sticky traps in various nurseries of plant raising Trials O, Q and R. Separation of means by LSD ($P<0.05$).

	Thrips injury	Trapped aphids		
Trial	H.	O.	Q.	R.
No cover	0.18 b	23 a	56 a	35 a
Plastic roof	0.62 a	-	-	-
Screen cover[*]	0.05 c	0 b	3 b	1 b
$LSD_{0.05}$	0.10	11	21	18

[*]Mesh 560-600 μm.

- = Not measured.

The proportion plantlets with virus symptoms at transplanting time was usually negligible. Only in Trial J, 17 % of the 2 months old plantlets in the non-covered nurseries showed clear virus symptoms, significantly more than the 0 % in the screen-covered nurseries ($LSD_{0.05}$=4).

Field. The development of yellow tea mite in the field was not influenced by nursery covers in Trials O, Q and R. In Trial O, the nursery period of 1½ month, however, had a significantly higher AUPPC for yellow tea mite than the other nursery periods. The *Cercospora* leaf spot epidemic, expressed as AUDPC, only showed a nursery effect in Trial Q, where the non-covered nursery had a significantly lower AUDPC than the screen-covered nursery. After transplanting, the start of the virus epidemic generally appeared to be delayed, as in Trial O (Figure 4.3), in plots with the screen-covered relative to those with non-covered nurseries. The intercept of the virus logit line was significantly lower (i.e. more negative) when plants had been raised in a screen-covered nursery in Trials O, Q and R. In Trial O, the intercept and the mid-value time were significantly larger when plants had been raised in non-covered nurseries for 2, compared to 1 and 1½ months.

Nursery covers did not influence the proportion of fruits affected by anthracnose fruit rot. The blossom mould epidemic in Trials Q and R, expressed as AUDPC, did not show nursery effects. The occurrence of southern blight was very patchy. No nursery effects were found. The total percentage of plants killed by southern blight in Trial O was 6 %.

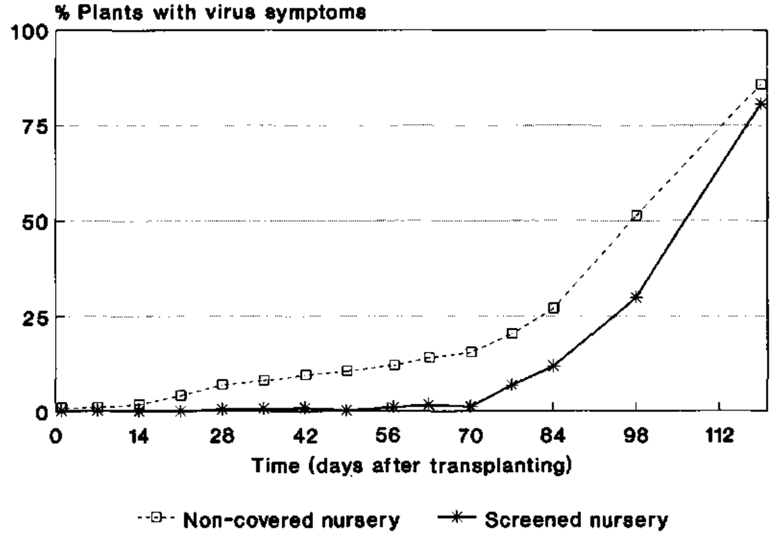

Figure 4.3. Progress of virus incidence in the field of hot pepper transplants, that originated from non-covered or screen-covered nurseries, in plant raising Trial O.

Crop production

The field crops of Trials H and J failed due to adverse weather conditions. Yield data from Trials A, E, O, Q and R are presented in Table 4.7. Trials A and E did not show differences between the nursery treatments, whereas in Trials O, Q and R healthy yield and mean weight per healthy fruit for the screen-covered nurseries were significantly higher than those of the non-covered nurseries. Screen covers caused significantly shorter mid-harvest times in Trials Q and R. In Trial O, healthy yield was highest for the 2 months nursery period in a screen-covered nursery. The mean fruit weight in the 1½ and 2 months nursery periods was 9.1 g, significantly higher than the 8.7 g in the 1 month nursery period ($LSD_{0.05}$=0.4). The 1½ months nursery period resulted in significantly shorter mid-harvest times than the 1 or 2 months nursery periods.

Table 4.7. Healthy yield, mean percentage healthy fruits, fruit weight and earliness of harvesting in five hot pepper plant raising trials. Healthy yield is expressed as the total weight of ripe, healthy fruits (t/ha), and fruit weight as the average weight per healthy fruit (g) of various nursery cover treatments. Earliness of harvesting is expressed as the mid-harvest time (days after transplanting) of various nursery covers and nursery periods. Separation of means by LSD (P<0.05).

Trial	A.	E.	O.		Q.		R.	
Healthy yield								
No cover	5.3	4.9	9.7	b	4.6	b	2.7	b
Plastic roof	6.3	4.9	-		-		-	
Screen cover*	-	5.3	13.1	a	6.0	a	4.0	a
$LSD_{0.05}$	-	-	2.0		0.6		0.8	
Mean % healthy fruits	-	73	88		77		45	
Fruit weight								
No cover	6.9	4.0	8.3	b	8.0	b	8.9	b
Plastic roof	6.8	4.0	-		-		-	
Screen cover*	-	4.1	9.1	a	8.3	a	9.6	a
$LSD_{0.05}$	-	-	0.4		0.2		0.7	
Earliness of harvesting								
No cover	89	111	104		109	a	94	a
Plastic roof	91	88	-		-		-	
Screen cover*	-	101	99		101	b	88	b
$LSD_{0.05}$	-	-	-		4		4	
1 Month period	-	-	106	a	-		-	
1½ Months period	-	-	97	b	-		-	
2 Months period	-	-	102	a	-		-	
$LSD_{0.05}$	-	-	4		-		-	

*Mesh 560-600 μm.
- = Not measured.

4.4 Discussion and conclusions

Results were variable and treatment effects were not consistent over all trials. The variability between trials was caused by differences in the environment at the locations Brebes, Subang and Klang, different weather, differences between cultivars, occurrence of pests and diseases, maintenance of trials, and so on. Nevertheless, some conclusions were drawn.

Superior plant raising techniques

Nursery cover. From the tested nursery covers, the screen cover proved most successful to enhance crop performance, health and production. Compared to non-covered nurseries, screen-covered nurseries produced higher numbers of healthy plantlets. Plantlets were taller and had more leaves. In the field, earliness of the crop was enhanced, as mid-fruiting and mid-harvest time values were shortened. The crop health in the field was influenced. An initial slow-down during the early phase of virus epidemics was found. The enhanced *Cercospora* leaf spot epidemic in the screen-covered nursery treatments of Trial Q is probably associated with fast crop development, as the phenological stages of fruiting and harvesting are most vulnerable to *Cercospora* leaf spot (Chapter 3).

Seed bed. In the field, potted transplants performed better than bare-root transplants. Crop establishment was improved and mid-fruiting time was shortened, indicating a reduction of the transplanting shock in case of potted transplants.

Nursery period. As expected, longer nursery periods resulted in taller plantlets with more leaves at transplanting. After transplanting, the crop performance was best in case of the 1½ months nursery period, as the need for replacements was reduced and fruiting and harvesting phases were advanced. The fastest crop growth was achieved by transplants from the 1½ months nursery period.

In Trial O, crop health was adversely affected when long nursery periods were combined with non-covered nurseries, since high incidence of viruses at, and fast build-up of the virus epidemic after transplanting could be observed. This phenomenon was delayed and slowed down when screen-covered nurseries were used. The delay of virus infection in the screen-covered nursery treatment during the initial field phase, is caused by the exclusion of aphids during the nursery phase. The virus epidemics as illustrated in Figure 4.3, advanced at the same speed only after about 70 days after planting. This phenomenon was found in other trials too, and is not well understood. It seems that transplants that were originating from screen-covered nurseries, and thus were growing and developing faster, were infested by aphids at a later stage than transplants from non-covered nurseries. Further research is needed to unravel the background of these nursery effects.

A peak in the yellow tea mite incidence in Trial O occurred at circa 2 months after transplanting. At that moment, the 1 and 2 months old transplants showed an almost zero plant height growth. The 1½ months old transplants were still growing. Perhaps, yellow tea mite incidence on these plants was higher because of a feeding preference of yellow tea mite for young leaves. This phenomenon was not found in other trials and needs verification.

Long nursery periods in screen-covered nurseries improved crop production, but not in non-covered nurseries.

Correlations between parameters of crop production and crop performance or crop health in the Trials O, Q and R are given in Table 4.8. It shows that short mid-fruiting times and fast plant growth are each correlated with high healthy yields, high healthy fruit weights and short mid-harvest times. Viruses display a negative correlation with healthy yield and healthy fruit weight, and delay harvesting. It is concluded that optimum raising of vigorous and healthy transplants can be achieved by using screen-covered nurseries, potting using banana leaf pots or plastic bags, and a nursery period of about 1½ months.

Feasibility

The screen and bamboo materials to construct screen-covered nurseries were easily available in the Brebes area in Central Java, Indonesia. The screen appeared durable and was expected to last four years or longer. Most probably, the use of pots will not present problems, since the use of potted transplants is already common practice in the highland vegetable production area of Lembang in West Java. The banana leaf pots are locally produced for this purpose.

Complete cost-benefit analyses are not available, but a few figures can be given. The cost of a screen-covered nursery with a bamboo frame was about IDR 1000/m^2 during 1990-1992 and banana leaf pots or plastic bags cost circa IDR 2 per piece (1 US$ ≈ 2000 IDR). Extra labour is required for plantlet raising and transplanting in the field when transplants are raised in pots, for potting and carrying potted instead of bare-root transplants to the field, but the labour required for replacing dead transplants is reduced. The costs of materials for screen-covered nurseries and pots were not returned through higher revenues during the first four plant raising trials. The Trials O, Q and R, however, showed that combinations of ICM practices during the plant raising phase with ICM practices in the field (light reflective mulching, need-based spraying) did result in significantly higher yields of healthy fruits. Excluding labour costs and using Indonesian price levels for materials, break-even prices of hot pepper in the Trials O, Q and R were below IDR 250/kg, while mean market prices were about IDR 580/kg in 1988.

Table 4.8. Linear correlations ($P<0.05$) between crop production, performance and health in three plant raising trials. Parameters of crop production are healthy yield (t/ha), mean healthy fruit weight (g/fruit) and mid-harvest time (days after transplanting). Parameters of crop performance are # plantlets (proportion transplants of the number of seeds sown at transplanting), crop establishment (complement of proportion transplants replaced in the field), plant height growth (cm/day), and mid-fruiting time (days after transplanting). Parameters of crop health are anthracnose fruit rot (% affected fruits), blossom mould (AUDPC in proportion.days), *Cercospora* leaf spot (AUDPC in proportion.days), southern blight (% affected plants), thrips (AUPPC in proportion.days), viruses (AUDPC in propotion.days) and yellow tea mite (AUPPC in proportion.days).

	Crop production								
	Healthy yield			Fruit weight			Mid-harvest time		
Trial	O.	Q.	R.	O.	Q.	R.	O.	Q.	R.
Crop performance									
# Plantlets	ns	-	ns	0.46	-	ns	ns	-	-0.47
Crop establishment	ns	ns	-	ns	ns	-	0.38	ns	-
Plant height growth	ns	ns	0.75	ns	0.32	0.48	-0.47	-0.45	ns
Mid-fruiting time	-0.54	-0.52	-0.72	-0.38	-0.47	-0.49	0.70	0.47	0.80
Crop health									
Anthracnose fruit rot	ns	-0.58	ns	ns	ns	ns	ns	-0.33	ns
Blossom mould	-	ns	ns	-	-0.40	0.49	ns	0.45	ns
Cercospora leaf spot	ns	ns	ns	ns	ns	ns	ns	-0.53	ns
Southern blight	-0.60	-	-	ns	-	-	ns	-	-
Thrips	-0.39	-0.56	ns	ns	-0.43	ns	ns	ns	ns
Viruses	ns	-0.40	-0.85	-0.48	-0.69	-0.67	ns	0.40	0.60
Yellow tea mite	-0.59	ns	ns	ns	ns	ns	ns	-0.33	ns

ns = Correlation is not significant.
- = Not determined.

Plant raising tactics as a component of ICM

The advantages of screen application during the nursery phase are the reduction of light, reduction of maximum air and soil temperature and the exclusion of aphids and thus of aphid-transmitted viruses. There is no need to spray pesticides in screen-covered nurseries. Seed treatment with a systemic pesticide can reduce initial parasite build-up (Jeffs, 1986) and reduce pesticide usage during the nursery phase. Relatively small quantities of antagonists or pesticides may be applied to the soil medium of potted plantlets for protection of the young crop in the field. Chamswarng (1992) treated tomato seedlings with *Trichoderma* spp. and found reduced incidence of southern blight under both field and greenhouse conditions. The risk of transferring soil-borne seed bed pests and diseases to the field can be excluded by using steam sterilized soil or sub-soil as a seed bed medium. Negative side-effects of the plant raising tactics recommended here, under screen cover in pots during 1½ months, are the screen and plastic wastes. These could be minimized through multiple use of screen-covered nurseries and use of recycled paper pots instead of plastic bags.

The advantages of ICM plant raising practices may be increased by the introduction of appropriate ICM practices during the field phase of the hot pepper cultivation, as will be discussed in the Chapters 5-7.

Chapter 5

Integrated crop management of hot pepper (*Capsicum* spp.) under tropical lowland conditions: effects of mulch on crop performance and production

J.G.M. Vos and N. Sumarni

Submitted.

Abstract: In the framework of research on integrated crop management (ICM) of hot pepper in tropical lowlands, effects of mulches were investigated. Mulch materials consisted of rice straw and white or silvery plastic foils. Physical effects of mulches were observed in soil temperature, light reflection, and soil nutrient concentrations after the last harvest. Crop performance was measured by the variables crop establishment, plant growth, and mid-fruiting time. Nutrient levels of leaves and fruits were assessed. Crop production was measured as yield of healthy fruits, mean weight of healthy fruits and mid-harvest time. Rice straw mulch reduced soil temperature, induced faster plant growth, advanced mid-fruiting time, and caused higher potassium contents in leaves, but effects on crop production were not found. Plastic mulches increased soil temperature, induced faster plant growth and earlier fruiting, reduced phosphorus concentrations in leaves and fruits, and increased nitrogen concentrations in leaves and fruits. Yield and mean fruit weight of healthy fruits were increased and earliness of harvesting was enhanced. The combination of improved crop performance and production with increase of fertilizer efficiency, control of evaporation, leaching and soil erosion by the plastic mulches fits in the concept of ICM. To minimize the negative side-effect of plastic waste on the environment, further improvement of the mulch technology is required. Preliminary field experiences and a tentative cost-benefit analysis are in favour of the application of plastic mulch in hot pepper under tropical lowland conditions.

5.1 Introduction

In Indonesia, hot pepper (*Capsicum* spp.) is the most important low elevation (below 200 m above sea level) vegetable commodity, in terms of cultivated area and production value (Chapter 1). Yields are low mainly due to the poor crop health. Farmers rely upon pesticides for crop protection (Chapter 2). To reduce the intensity of pesticide applications, more sustainable methods of crop protection were investigated. Integrated crop management (ICM) intends to improve crop growth and to reduce problems with pests and diseases. One component of ICM may be the application of mulch.

From a literature review, Hopen and Oebker (1976) concluded that application of a synthetic mulch could provide a method to repel certain insects, to control some soil pathogens and weeds, to modify soil temperature, to reduce evaporation, to control leaching of plant nutrients, to trigger plant growth and development and, as a result, to increase yield and improve product quality. Organic mulches reportedly reduce both soil temperature and evaporation, but do not invariably cause higher yields (Tukey and Schoff, 1963; Hill *et al.*, 1982; Famoso and Bautista, 1983; Olasantan, 1985; Midmore *et al.*, 1986; Kwon, 1988).

This chapter deals with the application of mulch as a component of hot pepper ICM under tropical low elevation conditions. The effects of organic and synthetic mulches on crop performance and production are reported. Effects of mulch on crop health are reported in Chapter 6.

5.2 Materials and methods

Experimental sites

Field trials were conducted at experimental sites of the Lembang Horticultural Research Institute (LEHRI) in Subang (West Java, 110 m above sea level), in Brebes and Tegal (Central Java, 10 m above sea level) in Indonesia and of the Malaysian Agricultural Research and Development Institute (MARDI) in Klang (Selangor Darul Ehsan, 3 m above sea level) in Malaysia.

Although Subang is not a vegetable production area, conditions are representative for dryland areas with vegetable production mainly during the rainy season. In Brebes and Tegal, locations in a major hot pepper production area, irrigation canals allow vegetable production during the dry season. The system of cambered beds and furrows (Ind.: *surjan*) is used. Klang represents areas where vegetables are produced continuously on peat soils. In Subang the soil is an acrisol/nitisol with a pH-H_2O of 5, in Brebes and Tegal a fluvisol with pH-H_2O 7, in Klang a histosol with pH-H_2O 4. Weather conditions during nine mulch trials, are summarized in Table 5.1.

Table 5.1. Overview of weather conditions during nine hot pepper mulch trials, indicating location, period, and averages of temperature, relative humidity, monthly rainfall and yield of healthy fruits.

Trial	Location	Period	Temperature (°C)		RH (%)		Rainfall	Yield
			Min	Max	Min	Max	(mm)	(t/ha)
B.	Brebes	Dec'89-Mar'90	23	31	66	97	284	2.7
C.	Subang	Jun'90-Sep'90	23	34	65	94	94	5.2
D.	Tegal	Jul'90-Nov'90	22	33	54	95	114*	9.5
F.	Subang	Feb'91-May'91	24	34	64	96	166*	4.2
I.	Subang	Aug'91-Dec'91	22	37	56	93	166	3.0
K.	Subang	Jan'92-May'92	22	35	64	98	316	-
P.	Klang	Aug'93-Dec'93	22	33	60	98	220	3.6
Q.	Klang	Aug'93-Jan'94	23	33	60	98	255	5.3
R.	Klang	Sep'93-Mar'94	23	33	57	97	272	2.3

*Possibly over- or underestimated due to temporary failure of equipment.
- = Missing data.

Mulch materials

Different mulch materials were selected. Rice straw was chosen as a representative of organic mulch. This material is usually burnt in the field after the rice harvest. One of the inorganic mulches was a woven fabric of white polypropylene (Ind.: *plastik karung*), commonly used in Indonesia for various purposes, such as fertilizer bags, or shelter material for market stalls. In this paper it will be referred to as 'woven fabric'. The woven fabric appeared to deteriorate in the field during crop cultivation, and a watertight white polyethylene plastic was added as a 'white plastic' mulch treatment. A third inorganic mulch was a plastic foil, silvery to grey coloured on one side and black on the other side (Ind.: *plastik hitam perak*). This 32 μm thick two-layer polyethylene, imported from Taiwan, was available in Jakarta and other large cities on Java in Indonesia, as well as in Kuala Lumpur and Port Klang in Malaysia. The silvery to grey colour is caused by a layer of finely dispersed aluminium powder. In the field it is applied with the silvery side up. In this paper it will be referred to as 'silvery plastic'.

Description of trials

The experimental design, factors and treatments of the conducted field trials are listed in Table 5.2. In the Trials B, C, D, F and I the hot pepper seed material, cultivar Tit Paris-LV 2699, originated from Brebes and represented a relatively homogeneous selection of the landrace Tit Paris. In Trial K the cultivar Jatilaba (East-West Seed Indonesia), a selection of the popular landrace Jatilaba from Brebes, was used. In the Trials P-R the MARDI cultivar MC4 was used. Further information on general cultivation techniques of the trials is given in Table 5.3.

Seeds were broadcasted on a seedbed, and after emergence transferred individually to pots or bags, in nurseries that were protected by aphid-proof screen. The nursery period lasted one month or longer. Raised plantlets were hardened in the open 3 to 5 days before transplanting. The field was prepared by harrowing the soil and constructing plant beds following the local practice. Plastic mulch was applied before and straw mulch after transplanting in the appropriate treatments. Fertilizer rates were according to LEHRI and MARDI recommendations, respectively, except in the Trials I, K, P and Q with nitrogen as additional experimental factor. Irrigation and weeding were conducted when necessary.

Cultivation practices of Trials F and P, representing trials in Indonesia and Malaysia respectively, are described in detail. In Trial F, plot size was 16.8 m^2, with 56 plants per plot. Lime, fertilizers (compost, nitrogen, potassium and phosphorus) and carbofuran (0.6 kg/ha) were applied in the plant holes before transplanting. The local spray schedule to control fungal diseases was adopted: mancozeb was sprayed 15 times and maneb 7 times. To control caterpillars, chlorfluazuron was applied 3 times. In Trial P, plot size was 36.0 m^2, with 60 plants per plot. The field was limed one month before transplanting. Fertilizers (organic manure, micro-nutrients, 1/3 of the nitrogen and potassium rates and phosphorus) were applied on the plant beds and carbofuran (1.0 kg/ha) was added to the plant holes before transplanting. The rest of the fertilizers (twice 1/3 of the nitrogen and potassium rates) were applied 1 and 2 months after transplanting in holes between the plants. To control pests and diseases, chemicals were applied only when necessary. Five dicofol sprays were applied to control mites and two copper hydroxide sprays to control fungal diseases. To control caterpillars, *Bacillus thuringiensis* was applied five times.

Table 5.2. Experimental design of nine hot pepper mulch trials with various experimental factors and treatments.

Trial	Design*	Replicates	Factors	Treatments
B.	SP	3	Mulch	No mulch
				Rice straw
				White woven fabric
				Silvery plastic
			Plant density	6 plants/m^2
				13 plants/m^2
C.	RCB	4	Mulch	No mulch
				Rice straw
				White woven fabric
				White plastic
				Silvery plastic
D.	RCB	4	Mulch	No mulch
				Rice straw
				White woven fabric
				White plastic
				Silvery plastic
F.	RCB	4	Mulch	No mulch
				Rice straw
				White woven fabric
				White plastic
				Silvery plastic
I.	RCB	4	Mulch	No mulch
				Rice straw
				White plastic
			Nitrogen	0 kg N/ha
				150 kg N/ha
				500 kg N/ha
K.	RCB	4	Mulch	No mulch
				White woven fabric
				Silvery plastic
			Nitrogen	0 kg N/ha
				150 kg N/ha
				500 kg N/ha
P.	RCB	4	Mulch	No mulch
				Silvery plastic
			Nitrogen	0 kg N/ha
				150 kg N/ha
				300 kg N/ha
				450 kg N/ha
Q.	RCB	5	Nursery	No screen cover
				Screen cover
			Mulch	No mulch
				Silvery plastic
			Nitrogen	200 kg N/ha
				300 kg N/ha
R.	RCB	5	Nursery	No screen cover
				Screen cover
			Mulch	No mulch
				Silvery plastic

*SP = Split-Plot; RCB = Randomized Complete Block.

Table 5.3. Cultural techniques, applied in nine hot pepper mulch trials, during nursery and field phases, among which cultivar choice, duration of the nursery period (days), number of plants per field plot, field plot size (m^2), number of chemical pesticides applications.

Trial	Cultivar	Nursery period (days)	# Plants/plot	Plot size (m^2)	Chemical pesticides
B.	Tit Paris	30	60/128	1.2*8.0	14 * Acaricide 14 * Fungicide 14 * Insecticide
C.	Tit Paris	30	56	4.2*4.0	9 * Acaricide 6 * Fungicide
D.	Tit Paris	30	80	1.2*5.0	15 * Fungicide
F.	Tit Paris	26	56	4.2*4.0	22 * Fungicide 3 * Insecticide
I.	Tit Paris	29	42	3.6*3.5	19 * Fungicide 22 * Insecticide
K.	Jatilaba	31	42	3.6*3.5	16 * Insecticide
P.	MC4	50	60	6.0*6.0	5 * Acaricide
Q.	MC4	44	60	6.0*6.0	5 * Acaricide 3 * Fungicide
R.	MC4	47	60	6.0*6.0	5 * Acaricide 5 * Fungicide

Observations

Light reflection between 200 and 1000 nm by the woven fabric, silvery and white plastic mulch materials was determined at AKZO (Fibres Division) in Arnhem, the Netherlands, using a CARY-05 spectrophotometer.

In Table 5.4, other observed characters are listed per trial. Soil temperature was measured randomly in the plant rows at 7, 12 and 17 hours at 10 cm depth, using a digital thermometer. After the last harvest, concentrations of nitrogen (N), potassium (K), phosphorus (P), carbon (C) and pH of the soil were assessed in soil samples, taken in plant rows (4 to 8 probes per plot), until 15 to 20 cm depth. Young mature leaves at second youngest nodes and ripening (about half red and half green) fruits were sampled at random several times for analyses of N, P and K.

Until 2 weeks after transplanting, the establishment of the crop was assessed as the complement of the quotient of replacements of dead transplants divided by the total number of plants, per plot. Observations on crop growth consisted of measuring plant height and counting branches on 10 marked plants per plot every two weeks. Crop development was observed by repeatedly counting proportions of plants with at least one fruit of more than 1 cm length, per plot. At each harvest, fruits were counted and healthy fruits were weighed. The healthy yield was recorded as the fresh weight of healthy, ripe fruits accumulated over all harvests, per plot. The mean weight per healthy

Table 5.4. Observed responses of hot pepper crop performance and analyses of soil and plant samples, during nine mulch trials.

Trial	Crop growth	Crop development	Analyses
B.	Establishment	-	-
	Branching		
	Plant height		
C.	Establishment	-	Soil temperature
	Plant height		Soil pH, N, P, K
D.	Establishment	-	Soil temperature
F.	Establishment	-	Soil temperature
	Branching		
	Plant height		
I.	Establishment	Fruiting	Soil temperature
	Branching	Fruiting	Soil pH, N, P, K, C
	Plant height		Leaf N, P, K
K.	Establishment	Fruiting	Soil pH, N, P, K
	Branching		Leaf N, P, K
	Plant height		Fruit N, P, K
P.	Establishment	Fruiting	Soil pH, N, P, K, C
	Plant height		Leaf N, P, K
			Fruit N, P, K
Q.	Establishment	Fruiting	Leaf N, P, K
	Plant height		Fruit N, P, K
R.	Plant height	Fruiting	-

- = Not observed.

fruit was calculated from the yield, divided by the accumulated number of healthy fruits. The earliness of harvesting was expressed in the mid-harvest time, the day that half of the total healthy yield was obtained.

Statistical procedures

Per plot, soil temperature observations were averaged for each time of the day. The successive data on branching were used to calculate linear ($Y=a+bX$; X = time in days after transplanting), the data on plant height and fruiting to calculate non-linear ($Y=a+bX+cX^2$) regression equations. The mid-fruiting time ($X_{Y=0.5}$) was calculated per plot. Average soil temperatures, average plant nutrient levels, rate parameters (b) of the branching and plant height equations, mid-fruiting times, and all other numerical data per plot were analyzed by means of Analysis Of Variance (ANOVA). Whenever significant differences ($P<0.05$) were found, the treatment means were separated using the Least Significant Difference (LSD) test.

5.3 Results

Light reflection (200 nm ≤ λ ≤ 1000 nm)

The white woven fabric reflected 25 to 60 % light between 200 and 300 nm and 25 to 30 % above 300 nm. The silvery plastic reflected 20 to 25 % light of all wavelengths. The white watertight plastic reflected 10 to 15 % light between 200 and 400 nm and 80 to 90 % above 400 nm. After some time in the field, the plastics started to become dull and light reflection was assumed to decrease. Equipment to measure heat reflection in situ was not available, but the silvery plastic felt hot suggesting emission of thermal radiation to the crop.

Soil data

At 12 and 17 hours, soil temperature under rice straw was significantly lower, compared to the 'no mulch' (bare soil) treatment. The white mulches caused significantly lower soil temperatures at noon in Trial C, but significantly higher soil temperatures in Trials D, F and I. Silvery plastic caused the highest soil temperatures at all times of the day (Figure 5.1). Soil analyses after the last harvest showed that pH and nutrient concentrations were not affected by mulching.

Crop performance

In Trials B and F, plastic mulch and in Trial F also straw mulch caused significantly worse crop establishment, compared to the bare soil treatment. In the seven other trials no significant effects on crop establishment were found.

Mulch effects on plant height were found in Trials C, I, K, P and R, indicating that rice straw and plastic mulches induced significantly faster growth than the bare soil treatment (Figure 5.2).

Analysis of the branching parameter showed that mulching significantly increased branching in Trials I and K. No effects on branching were found in Trials B and F.

In all trials, the mid-fruiting time was significantly shorter in mulched than in the bare soil treatment. In mulched treatments, the mid-fruiting time was reached up to 22 days (Trial P) earlier than in the bare soil treatment.

The analyses of plant material showed that concentrations of nitrogen in leaves in Trials K, P and Q were significantly higher in plastic mulched than in bare soil plots. Phosphorus concentrations in leaves were lower in plastic mulched than in bare soil plots in Trials I and P. Potassium concentrations in leaves were higher in rice straw mulched than in bare soil and plastic mulched plots in Trial I, and higher in plastic mulched than in the bare soil treatment in Trial K.

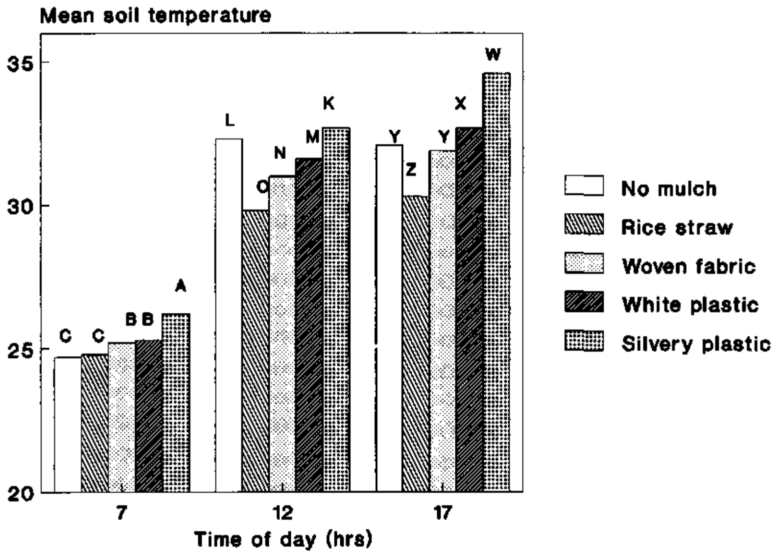

Figure 5.1. Soil temperature (°C) at 10 cm depth in various mulch treatments at three times of the day (hours) in mulch Trial C. Data are averages of 15 observations. Mean separation per time of the day by LSD ($P<0.05$).

Crop production

The yield of Trial K is not reported as it got partly lost due to non-technical problems. The use of plastic mulch invariably resulted in significantly higher healthy yields (Table 5.5). In the Trials C, F, I, P and R, yields in plastic mulched were double the yields in the bare soil treatment, or even more. Rice straw mulch did not increase yields. The fresh weight per fruit varied between trials, probably due to differences between cultivars and environmental conditions. The proportion of healthy fruits depended mainly on the occurrence of pests and diseases that injure fruits, such as fruit fly and anthracnose, which are discussed in Chapter 6.

In Trials B, C, P, Q and R, plastic mulch led to significantly heavier fruits than the bare soil or rice straw mulch treatment.

In Trials P, Q and R, mulching shortened the mid-harvest time significantly. The mid-harvest time was advanced 6 to 12 days.

The nitrogen concentrations in fruits were significantly increased in mulched plots in Trials P and Q. Phosphorus concentrations in fruits were significantly lower in mulched than in bare soil plots in Trial Q. There were no effects on potassium levels in fruits.

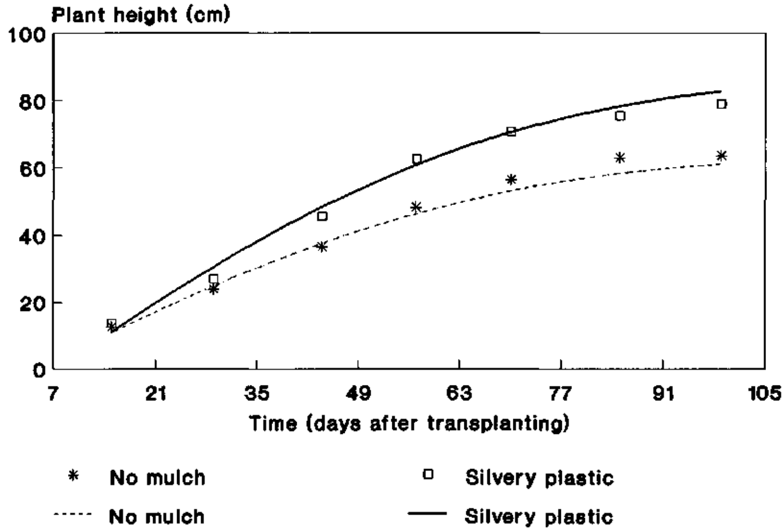

Figure 5.2. Observed and estimated values of hot pepper plant height in bare soil and silvery plastic mulched plots during mulch Trial P (Y = Plant height in cm; X = Time in days after transplanting).

$Y_{No\ mulch} = -7.1 + 1.28 * X - 0.006 * X^2$ ($r^2 = 0.93$)

$Y_{Silvery\ plastic} = -13.7 + 1.77 * X - 0.008 * X^2$ ($r^2 = 0.97$)

5.4 Discussion and conclusions

Some results proved consistent over trials, while others were variable. The variation between trials was caused by differences in the environment at the different experimental sites, weather, cultivars, occurrence of pests and diseases (Chapter 6), maintenance of trials, and so on. Several conclusions could be drawn.

Superior mulch type

Mulches influenced crop performance. White woven, silvery and white plastic mulches sometimes negatively affected crop establishment, but crop growth and development were generally promoted. Effects of the rice straw mulch were less prominent or absent.

Plastic mulches increased soil temperature. According to Gosselin and Trudel (1986), photosynthetic activity increases as root zone temperatures are raised. Comparing a temperature range of 12, 18, 24, 30 and 36 °C, they found maximum fruit yields of *Capsicum* at a constant soil temperature of 30 °C. The poor establishment in plastic mulch treatments in Trials B and F may be explained by the increased soil

Table 5.5. Average *healthy yield* (t/ha), average percentage of healthy fruits, mean weight per healthy fruit (g) and mid-harvest time (days after transplanting) of various mulch treatments in eight mulch trials. Mean separation by LSD ($P<0.05$).

Trial	B	C.	D.	F.	I.	P.	Q.	R.
Healthy yield								
No mulch	1.6 c	2.5 c	7.1 b	2.7 b	1.8 b	1.9 b	4.2 b	1.2 b
Rice straw	1.9 bc	3.7 bc	9.1 ab	2.9 b	1.9 b	-	-	-
Woven fabric	4.2 a	7.3 a	10.3 a	5.7 a	-	-	-	-
White plastic	-	7.0 a	11.3 a	4.4 a	5.3 a	-	-	-
Silvery plastic	2.9 b	5.4 ab	9.6 a	5.1 a	-	5.2 a	6.5 a	4.0 a
$LSD_{0.05}$	1.2	2.2	2.3	1.3	0.8	0.7	0.6	0.8
% Healthy fruits	84	83	94	61	97	67	77	45
Fruit weight								
No mulch	5.2 b	3.5 c	4.7	6.4	4.2	7.6 b	7.9 b	8.7 b
Rice straw	4.9 b	4.2 bc	4.9	6.3	4.2	-	-	-
Woven fabric	6.2 a	5.6 a	5.2	7.2	-	-	-	-
White plastic	-	4.9 ab	5.0	6.5	4.0	-	-	-
Silvery plastic	5.7 ab	4.8 ab	5.5	6.8	-	8.6 a	8.5 a	9.8 a
$LSD_{0.05}$	0.8	0.8				0.6	0.2	0.7
Mid-harvest time								
No mulch	95	85	84	83	99	117 a	108 a	94 a
Rice straw	97	85	86	83	99	-	-	-
Woven fabric	95	83	82	80	-	-	-	-
White plastic	-	84	82	80	99	-	-	-
Silvery plastic	95	83	82	81	-	105 b	101 b	88 b
$LSD_{0.05}$						3	4	4

- = Treatment not included in trial.

temperatures and reflection of light/heat. In the field, young plants experience a transplanting shock after sudden exposure to high light intensities and temperatures. As rice straw was applied after transplanting, mechanical injury imposed by the application of the rice straw after transplanting in Trial F may have contributed to the reduced survival in this treatment. In general, older hot pepper plantlets showed better crop establishment.

Increases in plant height rates due to mulching went together with increases in branching rates. Growth of bell pepper plants was found to be affected by changes in light environment due to surface colours of plastic mulches (Decoteau *et al.*, 1990). The mid-fruiting times showed that not only growth was enhanced by use of mulch, but also development. Due to earlier fruit set, mid-harvest values were shortened in the mulched treatments. Earliness may signify an economical advantage, if market prices are high early in the season and if labour peaks are acceptable.

An improvement in crop performance is generally associated with an increase of yield. Hwang and Lee (1978) found a highly positive phenotypic correlation between plant height and total fresh yield. Yi (1991) noticed that mulching with light reflecting plastic increased the photosynthetic activity in *Phaseolus* beans, contributing to higher yields. Total fresh weights of healthy fruits were indeed highest in plastic mulched treatments. Plots mulched with rice straw did not yield better than the bare soil treatment, even when they showed improved crop performance. Pests and diseases adversely affected crop production in the bare soil and rice straw treatments as described in Chapter 6. In general, plastic mulch positively affected fruit weight. The effect of mulching on this yield component may be due to increased photosynthetic activity and/or reduced problems with pests and diseases (Chapter 6). Effects of mulching on the earliness of harvesting were only observed in the trials in Malaysia, while the mid-fruiting time was advanced significantly in trials in Malaysia as well as in Indonesia. A proper explanation for this irregularity cannot be given but it was noted, especially in Malaysia, that mulched hot pepper produced earlier and deteriorated later compared to bare soil plots, indicating longer harvesting periods. In Trial P, nitrogen concentrations in fruits were higher in mulched than in bare soil plots. It was concluded that nitrogen uptake was improved by use of mulch. Provided that the recommended fertilizer rates were adequate, the reduced phosphorus concentrations in leaves and fruits of plastic mulched hot peppers cannot be explained.

In general, plastic mulch best improved crop performance and production. Woven fabric deteriorated during the crop cultivation period so that weeding was needed. Impermeable plastics were more durable and, from this point of view, better.

Technical feasibility

A preliminary on-farm experiment with 10 farmers in the hot pepper production area of Brebes (Central Java), testing rice straw mulch against bare soil treatments in fields of

80 to 100 m^2, showed some unexpected effects. The experiment was conducted during an extraordinary dry period in 1991, when the distribution system of irrigation water failed to supply the southern part of the region with sufficient water. Farmers' opinions in this southern area were positive about the straw mulch because yields were higher due to the increased water efficiency. Farmers in the northern area with sufficient water supply however, explained that their plants performed worse in the mulched treatments. Visits to these farmers' fields showed that the regular, overhead watering of the crop by hand at usual levels provided too much water to the plants, as mulch reduced evaporation. Water surplus possibly caused a lack of oxygen in the root zone. Plants wilting due to bacterial wilt were frequently observed. In the northern area, the yields of mulched plots were lower than yields of the bare soil plots. The transfer of mulch technology to farmers should therefore be accompanied by proper background information through regular extension.

In the low elevation area (below 200 m above sea level) around Magelang in Central Java, silvery plastic is incidentally applied by farmers who grow hot pepper and/or watermelon. According to the farmers, the plastic is mainly needed to control weeds and, in addition, to increase fertilizer efficiency and to prevent evaporation and soil erosion. The technology was introduced into the area about 1987 in combination with hot pepper seed material by a Taiwan-based private seed company. After the hot pepper crop, farmers do not remove the mulch, but use it for the next crop, for instance watermelon. Before this introduction, hot pepper was not a widely grown crop in the Magelang area.

Economical feasibility

Large scale adoption of mulch by farmers is primarily determined by economical considerations. Initial capital and labour input for the application of the mulch material should be paid back during the crop season as (1) labour for hand weeding and watering is reduced, (2) fertilizer efficiency is increased, (3) crop production is raised.

Complete cost-benefit analyses are not available, but a few figures can be presented. In 1990, prices of plastic mulch materials of 1.2 m wide were IDR 230, IDR 750 and IDR 240/m (1 US\$ ≈ 2000 IDR) for woven fabric, white and silvery plastic, respectively. In a cambered beds and furrows system, as in Brebes where only the beds need to be covered, mulching 1 ha would amount to circa IDR $1*10^6$ for woven fabric or silvery plastic and IDR $3.5*10^6$ for white plastic. In a dryland area, as in Subang, the costs would be higher, IDR $2*10^6$ and IDR $6.3*10^6$ respectively. Rice straw was acquired free from farmers in the neighbourhood. The initial extra labour needed to apply mulch is assumed to be less than the total labour required for weeding bare soil fields. Excluding labour costs, break-even prices ranged from IDR 353 to 668 for woven fabric and from IDR 432 to 800/kg hot pepper for silvery plastic in Indonesia. The white plastic was far too expensive. Mean hot pepper market prices were circa IDR 580/kg in 1988. In Malaysia (Trials P-R), break-even prices ranged from M\$ 0.45 to 0.65/kg hot pepper.

Mean market prices were circa M$ 2.35 in 1993.

It should be noted that, even though yields were within a normal range for the respective locations and seasons, recommended amounts of fertilizers usually differed from farmers' practices. In addition, restricted use of pesticides in the trials made results incomparable with farmers' practices. In Malaysia, a study was performed to compare traditional and IPM crop cultivation in farmers' fields. The IPM package consisted of a high yielding cultivar, protected transplant raising, use of silvery plastic mulch and restricted use of chemical pesticides. The IPM technology required larger inputs, but net-returns were higher than the traditional method (Anonymous, 1993).

In general, the mulch technology is expected to pay off, both in terms of money for the farmers and in terms of reduced use of nitrogen fertilizers, in hot pepper production areas where high amounts of fertilizers are applied. In production areas with low input farming, cheaper mulch materials are needed.

Mulching as a component of ICM

The advantages of mulch are manifold, due to the combination of the improvement of crop performance and production, and the reduction of leaching, evaporation and soil erosion. Thus, the mulch technology matches with the concept of ICM. The obvious possibility to reduce fertilizer dosages for mulched hot peppers must be further investigated.

A negative side-effect of inorganic mulch is the plastic waste after the last harvest. The silvery plastic contains aluminium, which may give undesirable residues. To control input costs and the amount of plastic waste, the mulch material may be used for two successive crops, such as hot pepper followed by watermelon. A future alternative would be the introduction of biodegradable mulch materials, when these become available.

Chapter 6

Integrated crop management of hot pepper (*Capsicum* spp.) under tropical lowland conditions: effects of mulch on crop health

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Crop Protection. Accepted.

Abstract: The effects of mulch on health of hot pepper crops were investigated in nine trials comparing various mulch treatments. Mulch materials consisted of rice straw and white or silvery plastic foils. Regular observations were made on anthracnose fruit rot, blossom mould, *Cercospora* leaf spot, oriental fruit fly, thrips, viruses, and yellow tea mite. Rice straw mulch had variable effects on crop health. White and silvery plastic mulch reduced thrips injury, and delayed virus epidemics. The overall positive effect of plastic mulch on crop health contributed to improved crop production. Mulching is therefore recommended as a component within an integrated crop management (ICM) programme for hot pepper.

6.1 Introduction

Pests and diseases impose severe constraints on the production of hot pepper (*Capsicum* spp.) in Indonesia. Major pests are cotton boll worm (*Heliothis armigera* Hübner), cotton jassid (*Empoasca lybica* de Bergevin and Zanon), oriental fruit fly (*Bactrocera dorsalis* Hendel), thrips (*Thrips parvispinus* Karny), tropical army worm (*Spodoptera litura* Fabricius) and yellow tea mite (*Polyphagotarsonemus latus* Banks). Major diseases are anthracnose fruit rot (*Colletotrichum* spp.), bacterial wilt (*Pseudomonas solanacearum* (Smith) Smith), *Cercospora* leaf spot (*Cercospora capsici* Heald and Wolf), southern blight (*Sclerotium rolfsii* Saccardo) and virus diseases, caused by among others cucumber mosaic virus (CMV) and chili veinal mottle virus (CVMV) (Chapter 3). Resistant cultivars are not yet available and farmers rely upon pesticides for crop protection (Chapter 2). In order to reduce pesticide usage, which can be extremely high, alternative and more sustainable methods of crop protection are investigated.

Integrated crop management (ICM) aims at improvement of crop growth and reduction of problems with pests and diseases. Mulch may be one component of ICM (Chapter 1). Hopen and Oebker (1976) concluded that the application of a synthetic mulch could provide a method to repel certain insects, to control some soil pathogens and weeds, to modify soil temperature, to reduce evaporation, to control leaching of plant nutrients, to trigger plant growth and development and, as a result, to increase yield and improve product quality. Organic mulches are reported to reduce soil temperature and evaporation, but do not invariably cause higher yields (Tukey and Schoff, 1963; Hill *et al.*, 1982; Famoso and Bautista, 1983; Olasantan, 1985; Midmore *et al.*, 1986; Kwon, 1988).

Effects of mulches on pests and diseases have been investigated in several crops. Table 6.1 lists results of studies on mulching and crop health of cabbage, common bean, cowpea, cucumber, eggplant, gladiolus, hot pepper, muskmelon, southern pea, squash, sweet pepper and tomato. An effect of mulch on beneficials was observed by Wolfenbarger and Moore (1968), who found an increase in frequency of honey bee visits in squash, mulched with aluminium or white material compared with the non-mulched control.

Table 6.1. List of reported effects of different mulch types on variables of crop health in various crops.

Phytophage	Crop	Type of mulch	Effect	Source(s)*
Pests				
Aphid	Cucumber	Aluminium, white plastic	Repellance	9, 15
	Hot pepper	Aluminium, clear plastic	Repellence	1
	Muskmelon	White plastic	Repellance	10
	Squash	Aluminium, white plastic	Repellence	4, 7, 12, 15
	Sweet pepper	Aluminium plastic	Repellence	2, 11
		Black plastic	No effect	2
Heliothis spp.	Tomato	Aluminium, white plastic	No effect	15
	Southern pea	Aluminium, white plastic	No effect	15
Leaf miner	Squash	Aluminium, blue, white plastic, brown paper	Control	4
Nezara spp.	Cowpea	Aluminium, white plastic	No effect	15
Thrips	Gladiolus	Aluminium foil	Control	16
	Sweet pepper	Aluminium plastic	Control	8
	Tomato	Aluminium plastic	Control	8
Diseases				
Black rot	Cabbage	Grass	Control	13
Southern blight	Common bean	Coconut fronds, black plastic	Delay of infection	14
	Sweet pepper	Black plastic	Control	3
Verticillium wilt	Eggplant	Black plastic	Delay of infection	6
Viruses, transmitted by				
Aphids	Cucumber	Aluminium, white plastic	Delay of infection	9, 15
	Hot pepper	Aluminium plastic	Delay of infection	1
	Muskmelon	White plastic	Delay of infection	10
	Squash	Aluminium, white plastic	Delay of infection	4, 7, 12, 15
	Sweet pepper	Aluminium plastic	Delay of infection	2, 11
Thrips	Sweet pepper	Aluminium plastic	Control	8
	Tomato	Aluminium plastic	Control	8
White flies	Tomato	Aluminium, blue, yellow plastic	Control	5

*Sources: 1. Ang (1984); 2. Black and Rolston (1972); 3. Brown *et al.* (1989); 4. Chalfant *et al.* (1977); 5. Cohen and Melamed-Madjar (1978); 6. Elmer and Ferrandino (1991); 7. George and Kring (1971); 8. Greenough *et al.* (1990); 9. Jones and Chapman (1968); 10. Lecoq and Pitrat (1982); 11. Loebenstein *et al.* (1975); 12. Moore *et al.* (1965); 13. Onsando (1987); 14. Reynolds (1970); 15. Schalk *et al.* (1979); 16. Smith *et al.* (1972).

Effects of mulch on crop growth and development and crop production are reported Chapter 5. This chapter deals with the application of mulch as a component of hot pepper ICM in tropical lowlands (below 200 m above sea level). The effects of organic and synthetic mulch on some major pests and diseases of hot pepper are described, such as anthracnose fruit rot, blossom mould, *Cercospora* leaf spot, oriental fruit fly, thrips, viruses, and yellow tea mite.

6.2 Materials and methods

Experimental sites

Field trials were conducted at experimental sites of the Lembang Horticultural Research Institute (LEHRI) in Subang (West Java, 110 m above sea level), Brebes and Tegal (Central Java, 10 m above sea level) in Indonesia and at the Malaysian Agricultural Research and Development Institute (MARDI) in Klang (Selangor Darul Ehsan, 3 m above sea level) in Malaysia. Although Subang is not a vegetable production area, conditions are representative for dryland areas with vegetable production mainly during the rainy season. In Brebes and Tegal, locations in a major hot pepper production area, irrigation allows vegetable production during the dry season. The system of cambered beds and furrows (Ind.: *surjan*) is used. Klang represents areas where vegetables are produced continuously on peat soils. In Subang the soil is an acrisol/nitisol with pH-H_2O 5, in Brebes and Tegal a fluvisol with pH-H_2O 7, in Klang a histosol with pH-H_2O 4. Weather conditions during nine mulch trials are summarized in Table 6.2.

Table 6.2. Overview of weather conditions during nine hot pepper mulch trials, indicating location, period, and averages of temperature, relative humidity, monthly rainfall and yield of healthy fruits.

Trial	Location	Period	Temperature (°C)		RH (%)		Rainfall	Yield
			Min	Max	Min	Max	(mm)	(t/ha)
B.	Brebes	Dec'89-Mar'90	23	31	66	97	284	2.7
C.	Subang	Jun'90-Sep'90	23	34	65	94	94	5.2
D.	Tegal	Jul'90-Nov'90	22	33	54	95	114*	9.5
F.	Subang	Feb'91-May'91	24	34	64	96	166*	4.2
I.	Subang	Aug'91-Dec'91	22	37	56	93	166	3.0
K.	Subang	Jan'92-May'92	22	35	64	98	316	-
P.	Klang	Aug'93-Dec'93	22	33	60	98	220	3.6
Q.	Klang	Aug'93-Jan'94	23	33	60	98	255	5.3
R.	Klang	Sep'93-Mar'94	23	33	57	97	272	2.3

*Possibly over- or underestimated due to temporary failure of equipment.
- = Missing data.

Description of trials

Four different mulch materials were selected, 'rice straw', 'woven fabric', 'white plastic' and 'silvery plastic' (Chapter 5). Rice straw was chosen as an organic mulch. The inorganic mulches were a woven fabric of white polypropylene (Ind.: *plastik karung*), a watertight white polyethylene plastic and a plastic foil, silvery to grey at the upper side and black at the lower side (Ind.: *plastik hitam perak*).

The experimental designs, factors and treatments of the field trials are listed in Table 6.3. In Trials B, C, D, F and I, the hot pepper seed material, cultivar Tit Paris-LV 2699, originated from Brebes and represented a relatively homogeneous selection of the landrace 'Tit Paris'. In Trial K, cultivar Jatilaba (East-West Seed Indonesia) was used, a selection of the popular landrace Jatilaba from Brebes. In Trials P, Q and R, the MARDI cultivar MC4 was used. Seeds were broadcasted on a seed bed, and after emergence transferred individually to pots or bags, in screen-covered nurseries. The nursery period was about 1 to 1½ month. Raised plantlets were hardened in the open 3 to 5 days prior transplanting in the field. The field was prepared, following the local practice, by harrowing the soil and making plant beds. Plastic mulch was applied before, and straw mulch after transplanting in the appropriate treatments. Fertilizer rates were according to LEHRI and MARDI recommendations, respectively, except in the two-factorial mulch x nitrogen trials (Trials I, K, P and Q). Irrigation and weeding were conducted when necessary. Further information on general cultivation techniques is given in Table 6.4. Cultivation practices in the Trials C and R, representing trials in Indonesia and Malaysia, respectively, are described in detail.

In Trial C, plot size was 16.8 m^2 with 56 plants per plot. The field was limed and fertilizers (goat manure, nitrogen, potassium and phosphorus) and carbofuran (0.5 kg/ha) were applied to the plant holes before planting. Weekly sprays to control fungal diseases were applied: propineb was sprayed twice and mancozeb 7 times. To control yellow tea mites propargit, dicofol and oxythioquinox were each sprayed twice.

In Trial R, plot size was 36.0 m^2 with 60 plants per plot. The field was limed one month before planting. Before planting, fertilizers (organic manure, micro-nutrients, 1/3 of the nitrogen and potassium rates and phosphorus) were applied on the plant beds and carbofuran (1.0 kg/ha) in the plant holes. The rest of the fertilizers (twice 1/3 of the nitrogen and potassium rates) were applied 1 and 2 months after planting in holes between the plants. To control pests and diseases, chemicals were applied need-based. To control caterpillars, *Bacillus thuringiensis* was applied once, to control yellow tea mite dicofol 5 times, and to control fungal diseases copper hydroxide 5 times.

Observations

Table 6.5 summarizes the responses observed during the mulch trials. After planting, blossom mould (*Choanephora cucurbitarum* (Berkeley & Ravenel) Thaxter), *Cercospora*

Table 6.3. Experimental design of nine hot pepper mulch trials with various experimental factors and treatments.

Trial	Design*	Replicates	Factors	Treatments
B.	SP	3	Mulch	No mulch
				Rice straw
				White woven fabric
				Silvery plastic
			Plant density	6 plants/m^2
				13 plants/m^2
C.	RCB	4	Mulch	No mulch
				Rice straw
				White woven fabric
				White plastic
				Silvery plastic
D.	RCB	4	Mulch	No mulch
				Rice straw
				White woven fabric
				White plastic
				Silvery plastic
F.	RCB	4	Mulch	No mulch
				Rice straw
				White woven fabric
				White plastic
				Silvery plastic
I.	RCB	4	Mulch	No mulch
				Rice straw
				White plastic
			Nitrogen	0 kg N/ha
				150 kg N/ha
				500 kg N/ha
K.	RCB	4	Mulch	No mulch
				White woven fabric
				Silvery plastic
			Nitrogen	0 kg N/ha
				150 kg N/ha
				500 kg N/ha
P.	RCB	4	Mulch	No mulch
				Silvery plastic
			Nitrogen	0 kg N/ha
				150 kg N/ha
				300 kg N/ha
				450 kg N/ha
Q.	RCB	5	Nursery	No screen cover
				Screen cover
			Mulch	No mulch
				Silvery plastic
			Nitrogen	200 kg N/ha
				300 kg N/ha
R.	RCB	5	Nursery	No screen cover
				Screen cover
			Mulch	No mulch
				Silvery plastic

*SP = Split-Plot; RCB = Randomized Complete Block.

Table 6.4. Cultural techniques, applied in nine hot pepper mulch trials, during nursery and field phases, among which cultivar choice, duration of the nursery period (days), number of plants per field plot, field plot size (m^2), number of chemical pesticides applications.

Trial	Cultivar	Nursery period (days)	# Plants/plot	Plot size (m^2)	Chemical pesticides
B.	Tit Paris	30	60/128	1.2*8.0	14 * Acaricide 14 * Fungicide 14 * Insecticide
C.	Tit Paris	30	56	4.2*4.0	6 * Acaricide 9 * Fungicide
D.	Tit Paris	30	80	1.2*5.0	15 * Fungicide
F.	Tit Paris	26	56	4.2*4.0	22 * Fungicide 3 * Insecticide
I.	Tit Paris	29	42	3.6*3.5	19 * Fungicide 22 * Insecticide
K.	Jatilaba	31	42	3.6*3.5	16 * Insecticide
P.	MC4	50	60	6.0*6.0	5 * Acaricide
Q.	MC4	44	60	6.0*6.0	5 * Acaricide 3 * Fungicide
R.	MC4	47	60	6.0*6.0	5 * Acaricide 5 * Fungicide

leaf spot, thrips, viruses and yellow tea mite were monitored by regularly counting plants with symptoms. Incidence was determined as the number of affected plants divided by the total number of plants, per plot. After observation, plant parts infected by blossom mould were removed, as a means of sanitation. Assessments of severity of *Cercospora* leaf spot and thrips were made using field keys, ranging from 0 to 5 (Chapter 3). Total numbers of fruits affected by anthracnose fruit rot were accumulated over all harvests, per plot. Fruit loss due to anthracnose fruit rot was expressed per plot as the proportion of diseased fruits relative to the total number of harvested fruits. The loss of fruits due to oriental fruit flies was assessed likewise.

Statistical procedures

The successive incidence observations on blossom mould and *Cercospora* leaf spot were used to calculate the Area Under the Disease Progress Curve (AUDPC), expressed in 'proportion-days', per disease and per plot. AUDPC is the disease intensity integrated over time between two observation dates, using the trapezoidal integration method (Campbell and Madden, 1990). The yellow tea mite incidence and thrips incidence and severity data were integrated in the same way, leading to Area Under the Pest Progress Curve (AUPPC), per pest and per plot.

The virus incidence data per plot were transformed into logits ($Y'=\ln[Y/(1-Y)]$; Y = proportion diseased). Logit values were subjected to linear regression on time to

Table 6.5. Observed responses of variables of hot pepper crop health in nine mulch trials.

Trial	B	C	D	F	I	K	P	Q	R
Pests									
Oriental fruit fly	-	+	-	-	+	+	+	+	+
Thrips									
severity	+	-	+	-	+	-	-	-	-
incidence	-	-	-	-	-	-	+	+	-
Yellow tea mite	+	+	+	-	-	-	+	+	+
Diseases									
Anthracnose fruit rot	+	+	-	+	-	+	+	+	+
Blossom mould	-	-	-	-	-	-	+	+	+
Cercospora leaf spot									
severity	+	-	-	-	-	+	-	-	-
incidence	-	-	-	-	-	+	+	+	+
Viruses	-	+	+	+	+	+	+	+	+

+ = Observed; - = Not observed.

describe the progress of the natural epidemic (Van der Plank, 1963). Virus mid-value times ($X_{Y=50\%}$ in days after transplanting) were calculated per plot.

All numerical data, AUDPC's and AUPPC's, regression parameters and mid-value times per plot were subjected to Analysis Of Variance (ANOVA). Whenever significant differences were encountered ($P<0.05$), the treatment means were separated using the Least Significant Difference (LSD) test.

Relations between crop health and crop production were determined per trial through linear correlation over experimental treatments. Variables of crop production were healthy yield, percentage healthy fruits and harvest mid-value time, per plot, as reported in Chapter 5. Variables of crop health were loss of fruits due to anthracnose fruit rot, blossom mould AUDPC, *Cercospora* AUDPC, loss of fruits due to oriental fruit fly, thrips AUPPC, virus mid-value time, yellow tea mite AUPPC, per plot.

6.3 Results

Effects on injury and damage by pests

Oriental fruit fly. The damage caused by oriental fruit fly in the trials in Indonesia was most serious during rainy seasons. In Trial I, during the dry season, mulching significantly reduced oriental fruit fly damage from 4 % in the control to 2 % in rice straw or white plastic mulched plots ($LSD_{0.05}$=2 %) (Table 6.6). In the trials in Malaysia, oriental fruit fly was not important since the loss of fruits due to oriental fruit fly was 1 % or less. Even though, in Trial Q, mulching significantly increased oriental fruit fly damage, the amount was negligible (0.3 %; $LSD_{0.05}$=0.2 %).

Table 6.6. Percentage fruit loss due to oriental fruit fly or anthracnose fruit rot in mulch Trials B, C, F, I, K, P, Q and R. Mean separation by LSD (P<0.05).

Mulch \ Trial	B	C	F	I	K	P	Q	R
Oriental fruit fly								
No mulch	-	10	-	4 a	15	1	0 b	1
Rice straw	-	19	-	2 b	-	-	-	-
Woven fabric	-	10	-	-	16	-	-	-
White plastic	-	9	-	2 b	-	-	-	-
Silvery plastic	-	14	-	-	14	1	1 a	1
$LSD_{0.05}$	-	-	-	2	-	-	0.2	-
Anthracnose fruit rot								
No mulch	8	1 b	5	-	63	31 a	21	48
Rice straw	6	1 b	4	-	-	-	-	-
Woven fabric	6	3 a	7	-	62	-	-	-
White plastic	-	3 a	7	-	-	-	-	-
Silvery plastic	6	5 a	10	-	63	22 b	19	53
$LSD_{0.05}$	-	2	-	-	-	4	-	-

- = Not observed or treatment not included in trial.

Thrips. The AUPPCs of thrips severity or incidence in Trials B, D, I, P and Q were significantly lower in the plastic mulched plots (Table 6.7). Rice straw mulching led to a significant reduction of severity AUPPC in Trial B only. Figure 6.1 illustrates the reduction of thrips incidence by silvery mulch as well as the effect of rain. Thrips is especially problematic during dry periods. During rainy periods, thrips incidence is reduced as can be seen in Figure 6.1 where the thrips incidence curve in the bare soil treatment declines sharply after two heavy rains at 25 and 31 days after transplanting.

Yellow tea mite. In Trials B and C, yellow tea mite was chemically controlled when the incidence increased to about 10 % or more, at 45 and 26 days after planting, respectively. Analysis of yellow tea mite incidence until the first acaricide application showed that in Trial B plastic mulches significantly reduced yellow tea mite incidence compared to the bare soil treatment. In Trial C there were no significant differences. In

Table 6.7. Thrips severity in mulch Trials B, D and I, and thrips incidence in mulch Trials P and Q, transformed to AUPPC (in proportion.days). Mean separation by LSD (P<0.05).

Mulch \ Trial	B	D	I	P	Q
No mulch	262 a	75 a	99 a	1518 a	486 a
Rice straw	235 b	75 a	95 a	-	-
Woven fabric	154 c	60 b	-	-	-
White plastic	-	50 b	73 b	-	-
Silvery plastic	172 c	58 b	-	412 b	31 b
$LSD_{0.05}$	23	13	6	235	88

- = Treatment not included in trial.

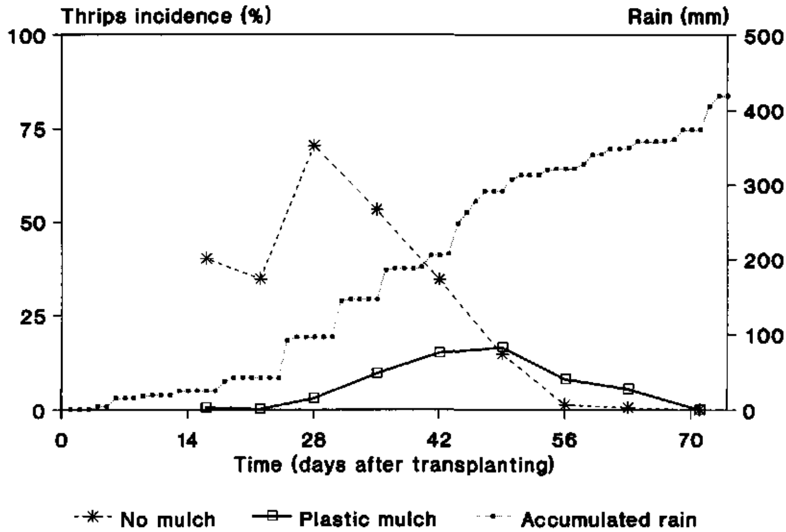

Figure 6.1. Mulch Trial P. Incidence of thrips (% infested plants) in non-mulched and silvery plastic mulched plots and accumulated daily rainfall data versus time (days after transplanting).

Trial D, yellow tea mite incidence was low, acaricides were not applied, and no significant differences were found. In Trials P, Q and R, yellow tea mites were chemically controlled initially by localized applications of infested plants. When the infestation with yellow tea mite had spread to more than about 10 % of the plants, full field sprays were applied. No significant differences were found between plastic mulched and bare soil plots.

Effects on injury and damage by diseases

Anthracnose fruit rot. Anthracnose fruit rot was a major problem during rainy periods. Yield losses were relatively low in Trials B, C and F, because the cultivar Tit Paris is not so susceptible. In Trial C, plastic mulches increased anthracnose fruit rot significantly from 1 % in the bare soil treatment to 3-5 % in the mulched plots ($LSD_{0.05}$=2 %) (Table 6.6). In Trial K the susceptible cultivar Jatilaba was used and no fungicides were applied, resulting in a substantial loss of fruits. Unfortunately, one harvest of Trial K was lost due to non-technical problems. Based on the available data, the average fruit loss was 63 %, without significant differences between treatments. In Trials P, Q and R, average fruit losses amounted to 27, 20 and 51 %, respectively. In Trial P, silvery plastic reduced anthracnose fruit rot incidence significantly from 31 % in the control to 22 % ($LSD_{0.05}$=4 %). Trials Q and R showed no significant differences between mulch treatments.

Blossom mould. Blossom mould was problematic during rainy periods of the trials in Malaysia. In Trial Q, the AUDPC was significantly lower in mulched plots than in the bare soil treatment. Figure 6.2 shows that the blossom mould epidemic is delayed in mulched plots and that incidence decreased as plants grew older. Similar effects appeared in Trials P and R, but AUDPCs did not show significant differences.

Cercospora leaf spot. The AUDPC of *Cercospora* leaf spot severity was significantly reduced in the mulched plots of Trial B (Table 6.8), but not in Trial K. The incidence of *Cercospora* leaf spot in Trial K was significantly lower in mulched plots than in the bare soil treatment. Apparently, there was an initial delay of the epidemic. In Trial P, the

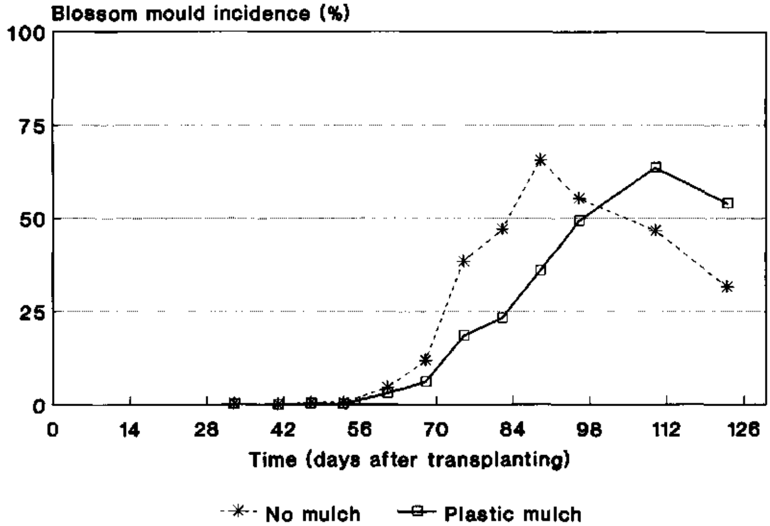

Figure 6.2. Mulch Trial Q. Incidence of blossom mould (% infected plants) in non-mulched and silvery plastic mulched plots versus time (days after transplanting).

epidemic was enhanced slightly and the incidence AUDPC in the mulched treatment was significantly higher than in the bare soil treatment. Trials Q and R had no significant differences in *Cercospora* leaf spot incidence between bare soil and mulched plots.

Viruses. The mid-value time of virus incidence ($X_{Y=50\%}$) was significantly longer in plastic mulched plots than in bare soil or rice straw mulched plots (Table 6.9, Figure 6.3), meaning that plastic mulch caused significant delays in virus epidemics. Growth rates of virus epidemics did not differ significantly between treatments in Trials C, D, F, I, K and P. In the silvery plastic mulched plots of Trial R, the epidemic growth rate was significantly reduced and in Trial Q significantly increased.

Table 6.8. *Cercospora* leaf spot severity in mulch Trial B and *Cercospora* leaf spot incidence in mulch Trials K, P, Q, and R, transformed to AUDPC (in proportion.days). Mean separation by LSD (P<0.05).

Mulch \ Trial	B		K		P		Q	R
No mulch	205	a	2996	a	869	b	1409	1346
Rice straw	168	b	-		-		-	-
Woven fabric	132	c	2402	b	-		-	-
Silvery plastic	144	bc	2504	b	1056	a	1374	1286
$LSD_{0.05}$	28		258		163		-	-

- = Treatment not included in trial.

Table 6.9. Virus incidence mid-value times (days after transplanting) in seven mulch trials. Mean separation by LSD (P<0.05).

Mulch \ Trial	C		D		I		K		P		Q		R	
No mulch	26	b	18	b	26	b	19	b	55	b	48	b	31	b
Rice straw	25	b	20	b	27	b	-		-		-		-	
Woven fabric	43	a	24	a	-		54	a	-		-		-	
White plastic	37	a	25	a	43	a	-		-		-		-	
Silvery plastic	37	a	25	a	-		53	a	83	a	68	a	53	a
$LSD_{0.05}$	7		4		3		6		5		5		5	

- = Treatment not included in trial.

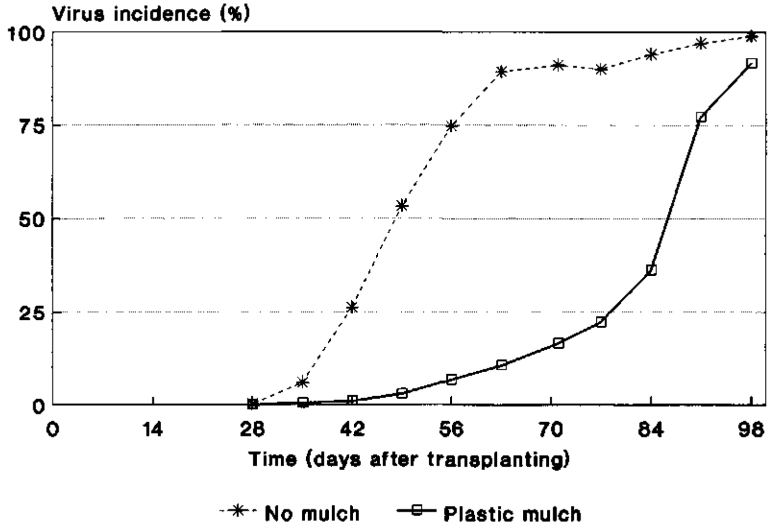

Figure 6.3. Mulch Trial P. Virus incidence (% plants with symptoms) in non-mulched and silvery plastic mulched plots versus time (days after transplanting).

Crop health correlated with crop production

Table 6.10 lists results of linear correlation between variables of crop health and variables of crop production. Thrips injury and earliness of virus epidemics were negatively correlated with yield in all and in five out of seven trials, respectively. In addition, virus mid-value time was negatively correlated with the harvest mid-value time in four out of seven trials. Oriental fruit fly and anthracnose fruit rot were negatively correlated with the proportion healthy fruits in three out of four and five out of seven trials, respectively. Correlations of yellow tea mite, blossom mould and *Cercospora* leaf spot with parameters of crop production were not significant or not consistent.

Table 6.10. Coefficients of linear correlation ($P<0.05$) between variables of crop production (yield of healthy fruits (t/ha), % healthy fruits, earliness (harvest mid-value time in days after transplanting)) and variables of crop health (% fruits affected by oriental fruit fly, thrips AUPPC (proportion.days), yellow tea mite AUPPC (proportion.days), % fruits infected with anthracnose fruit rot, blossom mould AUDPC (proportion.days), *Cercospora* leaf spot AUDPC (proportion.days), virus mid-value time (days after transplanting)), in nine mulch trials.

Variables \ Trial	B	C	D	F	I	K	P	Q	R
Healthy yield (t/ha)									
Anthracnose fruit rot	-0.53	ns	-	ns	-	-	ns	-0.58	ns
Blossom mould	-	-	-	-	-	-	ns	ns	ns
Cercospora leaf spot	ns	-	-	-	-	-	0.39	ns	ns
Oriental fruit fly	-	-0.45	-	-	ns	-	ns	-	-
Thrips	-0.61	-	-0.59	-	-0.70	-	-0.63	-0.56	-
Viruses	-	0.51	ns	0.71	0.77	-	0.74	ns	0.79
Yellow tea mite	-0.55	ns	ns	-	-	-	ns	ns	ns
% Healthy fruits									
Anthracnose fruit rot	-0.66	ns	-	ns	-	-0.57	-0.96	-0.98	-0.95
Blossom mould	-	-	-	-	-	-	ns	ns	ns
Cercospora leaf spot	ns	-	-	-	-	ns	ns	ns	ns
Oriental fruit fly	-	-0.94	-	-	-0.88	-0.37	ns	-	-
Thrips	ns	-	ns	-	ns	-	ns	ns	-
Viruses	-	ns	ns	ns	ns	ns	0.52	ns	ns
Yellow tea mite	ns	ns	ns	-	-	-	ns	ns	ns
Earliness									
Anthracnose fruit rot	ns	ns	-	ns	-	-	ns	-0.33	ns
Blossom mould	-	-	-	-	-	-	ns	-0.45	ns
Cercospora leaf spot	ns	-	-	-	-	-	ns	-0.53	ns
Oriental fruit fly	-	ns	-	-	ns	-	ns	-	-
Thrips	ns	-	ns	-	ns	-	0.78	ns	-
Viruses	-	ns	ns	-0.50	ns	-	-0.58	-0.38	-0.63
Yellow tea mite	ns	ns	ns	-	-	-	ns	-0.33	ns

- = Not observed; ns = Not significant.

6.4 Discussion and conclusions

The results of observed variables of crop health were not always consistent. Variables were categorized into classes with consistent or inconsistent results. Variables which, in the majority of trials, showed similar significant differences between mulch treatments or significant correlations with variables of crop production in Table 6.10, were categorized as consistent results. Variables with only few significant or with contradicting results were categorized as inconsistent results. Only consistent results have generalization value. They can be used, after further confirmation, for recommendations to farmers.

Crop health, consistent results

Thrips. The consistent plastic mulch effect of reducing of thrips injury (Table 6.7) may be related to the reflection of light by the plastic mulches. According to Lewis (1973) repellency could be associated with disturbance of orientation before landing. Another possibility is the reduced access to suitable pupation sites in the soil under the crop. The thrips AUPPC was negatively correlated with yield in all trials (Table 6.10), leading to the conclusion that the negative effect of plastic mulches on thrips contributed to yield increases.

Virus. The delays that plastic mulches caused to virus epidemics (Table 6.9) confirm earlier reports. Black and Rolston (1972), Cohen (1982), George and Kring (1971), Johnson *et al.* (1967), Loebenstein *et al.* (1975), Moore *et al.* (1965), Ang (1984) and Smith and Webb (1969) attribute the delay in virus epidemics to the repelling effect of light reflecting mulches on virus vectors. Rice straw mulch did not delay virus epidemics. The predominant virus of hot pepper in Subang was CMV, which is transmitted by many species of aphids. Aphid repelling effects of the mulches could not be demonstrated. Mulch effects were reduced when the crop canopy closed, which obviously caused a reduction in the reflection of light by the mulches. In most trials, virus incidence eventually reached high levels in all mulch treatments. Yield reductions due to late virus infections are generally less than those due to early infections (Agrios *et al.*, 1985; Ang *et al.*, 1980). In this chapter too, lateness of virus infection (i.e. long virus mid-value time) was positively correlated with yield (Table 6.10). The low yields in rice straw mulched plots may be attributed to the lack of response of virus vectors to rice straw mulch.

Crop health, inconsistent results

Oriental fruit fly. The mulch effect in Trial I, with less oriental fruit fly damage in the treatments with rice straw or white plastic mulch, was not confirmed in other trials (Table 6.6). A mulch effect was expected as Katsoyannos (1989) found fruit flies to respond positively to colours between 500 and 600 nm (green, yellow, orange). Light below 500 nm (blue, violet, ultraviolet) was least attractive to fruit flies. Another factor of attraction might be a large size of fruits as was found for *Bactrocera oleae* (Katsoyannos, 1989). In Trial I, however, no mulch effects on average fruit weight were found. The high negative correlations between oriental fruit fly injury and percentage healthy fruits (Table 6.10) in Trial C and I were to be expected, as in these trials a large part of the unhealthy fruits was infested with oriental fruit fly.

Yellow tea mite. The reduction of yellow tea mite incidence by plastic mulch in Trial B was not confirmed in other trials. Chemical control probably interfered with mulch effects, if any.

Anthracnose fruit rot. The mulch effect on anthracnose fruit rot was variable. Anthracnose fruit rot was significantly reduced in Trial P, increased in Trial C and not affected in the other trials by plastic mulches (Table 6.6). Using a (partially) resistant cultivar appeared more promising than the mulch effects of Trial P. The high negative correlation with the percentage healthy fruits in Trials P, Q and R (Table 6.10) was due to the low incidence of other fruit injuring factors in those trials.

Blossom mould. Blossom mould infections appeared delayed in plastic mulched plots (Figure 6.2). The delay of the epidemic may be caused by induced resistance of mulched plants. Blossom mould incidence reduced as plants started to age since the fungus occurs on young succulent shoots only. It was observed that mulched plants started to age later than non-mulched plants. The delayed reduction of blossom mould appeared to be related to the delayed senescence of plants.

Cercospora leaf spot. Trial B showed a reduced severity of *Cercospora* leaf spot in rice straw or plastic mulched plots, and Trial K a delayed build-up of the epidemic in the plastic mulched treatments (Table 6.8). However, the disease was enhanced by plastic mulch in Trial P. Two different processes may be involved. Firstly, infection of the crop with soil-borne diseases, such as *Cercospora* leaf spot, through soil splashing can be reduced by covering soil with mulch, causing a delay of the epidemic. Secondly, *Cercospora* leaf spot develops during fruit set and later stages of the crop (Chapter 3). As plastic mulch promotes earliness (Chapter 5), earlier epidemics can be expected. The resultant of two counteracting processes may show a capricious behaviour.

Mulching as a component of ICM

Consistent results showed that thrips injury was reduced and virus epidemics were delayed by plastic mulch. At times, mulching can influence anthracnose fruit rot, blossom mould and *Cercospora* leaf spot. Mulches of white or silvery coloured plastic promoted crop health. The use of pesticides could be reduced, as chemical control of thrips and virus-vectors appeared unnecessary in plastic mulched plots. Localized chemical control of yellow tea mite on infected plants fits in with ICM and appeared feasible up to 10 % incidence. The advantage of improved crop health, reduced need for chemical control and increased crop production show that mulching can be used as a component of ICM.

Chapter 7

Nitrogen fertilizing as a component of integrated crop management of hot pepper (*Capsicum* spp.) under tropical lowland conditions

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Submitted.

Abstract: Within the scope of research on integrated crop management (ICM) of hot pepper in tropical lowlands, effects of nitrogen fertilization were studied. In field trials, treatments with various nitrogen application rates between 0 and 500 kg N/ha were combined with mulch treatments in factorial trials. Nutrient levels of leaves and fruits were analyzed. Crop performance was monitored as plant height, branching and fruiting time, and crop health as incidence and severity of pests and diseases. Crop production was measured as yield of healthy fruits, mean weight of healthy fruits, and mid-harvest time. In pot experiments in a growth chamber, effects of nitrogen application rates on severity of *Cercospora* leaf spot were studied. Nitrogen fertilization improved plant growth, but did not influence fruiting time. Increasing nitrogen application rates aggravated *Cercospora* leaf spot in the growth chamber trials. Negative correlations between nitrogen levels in leaves and incidence of blossom mould and thrips were found. Moderate nitrogen applications (150 kg N/ha) gave best yields in most field trials. Mean fruit weight and mid-harvest time were not affected by the amount of nitrogen applied. With increasing nitrogen application rates, higher nitrogen levels in both leaves and fruits were found. Moderate amounts of nitrogen, balanced with proper amounts of phosphorus and potassium are recommended as a fertilizer component of ICM.

7.1 Introduction

Research on integrated crop management (ICM) was initiated to alleviate crop health problems of hot pepper (*Capsicum* spp.) in Indonesia (Chapter 1). The nutrition of the crop affects crop performance, its resistance to pests and diseases, and crop production. Exploratory surveys in Indonesia's major hot pepper production areas on the island of Java revealed that farmers generally applied unbalanced fertilization with, in several cases, extremely high nitrogen (N) rates (Chapter 2).

Thomas and Heilman (1964) found that N fertilization increased the N content of young mature leaf tissue, and improved fruit yield of *Capsicum*. Macro-nutrient accumulation studies on *Capsicum* showed that N and potassium (K) were absorbed in large amounts, while calcium (Ca), magnesium (Mg) and phosphorus (P) were needed in smaller quantities (Miller *et al.*, 1979; Vimala *et al.*, 1985; Van Goor, 1988). According to Perrenoud (1977), excessive use of N implies lack of nutrient balance and, in the context of crop health, a correct balancing especially of N and K is important.

Effects of N supply on the severity of pests and diseases have been studied in many crops. Waring and Cobb (1992) reviewed effects on herbivore population responses. They found that 60 % of 186 fertilization studies reported positive and 11 % negative responses to N fertilization. N is essential for production of e.g. proteins and phytoalexins, and influences the amount of cellulose and thus the mechanical strength of cell walls. According to Huber and Watson (1974), control of diseases by manipulation of N fertilization is caused by increased host resistance, altered virulence or growth of the pathogen, biological control through soil microfloral interactions, or a combination of these factors.

In Indonesia, major hot pepper pests are cotton boll worm (*Heliothis armigera* Hübner), cotton jassid (*Empoasca lybica* de Bergevin and Zanon), oriental fruit fly

(*Bactrocera dorsalis* Hendel), thrips (*Thrips parvispinus* Karny), tropical army worm (*Spodoptera litura* Fabricius) and yellow tea mite (*Polyphagotarsonemus latus* Banks). Predominant diseases are anthracnose fruit rot (*Colletotrichum* spp.), bacterial wilt (*Pseudomonas solanacearum* (Smith) Smith), *Cercospora* leaf spot (*Cercospora capsici* Heald & Wolf), southern blight (*Sclerotium rolfsii* Saccardo) and aphid-transmitted viruses, especially cucumber mosaic virus (CMV) and chili veinal mottle virus (CVMV) (Chapter 3).

Asandhi and Koestoni (1989) found an increase in anthracnose fruit rot damage on hot pepper, fertilized with an increased amount of N, compared to standard recommendations. According to Lewis (1973), a high proportion of N compounds makes the leaf tissue a rich source of nutrients for thrips. On the other hand, Kelman (1950) found that high N levels, above the optimum for growth, depressed bacterial wilt development in tobacco. In addition, N fertilizers could reduce southern blight disease incidence due to suppression of saprophytic activity of *Sclerotium rolfsii* in soil (Avizohar-Hershenzon and Shacked, 1969).

Previous research with organic and plastic mulches showed improved crop health, performance and production, especially when reflective plastic mulch was applied (Chapters 5 and 6). Mulching leads to more efficient use of nutrients due to the control of leaching. Because interactions between N application rates and mulch were expected, N treatments were combined with mulch treatments in factorial trials. This chapter reports on the effects of N fertilizing on crop performance, crop health and crop production. Effects of different N application rates on crop growth, development, some major pests and diseases, and yield parameters in five field trials are described. In addition, two growth chamber studies on effects of N on plant growth and disease development are reported.

7.2 Materials and methods

Experimental sites

Three field trials with various levels of N fertilization were conducted at the Lembang Horticultural Research Institute (LEHRI) experimental garden in Subang (West Java, 110 m above sea level), Indonesia. LEHRI Subang represents dryland areas with vegetable production mainly during the rainy season. The soil is an acrisol/nitisol with a pH-H_2O of 5. Two field trials were carried out at the Malaysian Agricultural Research and Development Institute (MARDI) experimental garden in Klang (Selangor Darul Ehsan, 3 m above sea level), Malaysia. MARDI Klang represents peat soil areas with continuous vegetable cultivation. The soil is a histosol with a pH-H_2O of 4. Temperature, humidity and rainfall data, collected during subsequent field trials are presented in Table 7.1. N effects were also tested in two pot experiments in a growth chamber at Wageningen

Agricultural University (WAU), the Netherlands, at 25 °C, 80 % RH, circa 14,000 lux, and 12 h day length.

Table 7.1. Overview of weather conditions during seven hot pepper nitrogen trials, with indication of location, period, and averages of temperature, relative humidity, monthly rainfall and yield of healthy fruits.

Trial	Location	Period	Temperature (°C)		RH (%)		Rainfall	Yield
			Min	Max	Min	Max	(mm)	(t/ha)
G	Subang	Feb'91-Jun'91	24	34	64	96	111*	3.1
I	Subang	Aug'91-Dec'91	22	37	56	93	166	3.0
K	Subang	Jan'92-May'92	22	35	64	98	316	-
L	Wageningen	Jul'92-Dec'92	25		80		-	-
M	Wageningen	Nov'92-Apr'93	25		80		-	-
P	Klang	Aug'93-Dec'93	22	33	60	98	220	3.6
Q	Klang	Aug'93-Jan'94	23	33	60	98	255	5.3

*Possibly over- or underestimated due to temporary failure of equipment.
\- = Missing data or not applicable.

Description of trials

Field trials. Experimental designs, factors and treatments of the conducted trials are listed in Table 7.2. The hot pepper cultivar in Trials G and I was Tit Paris-LV 2699, a relatively homogeneous selection of the landrace Tit Paris from Brebes. In Trial K cultivar Jatilaba (East West Seed Indonesia) was used, a selection of the popular landrace Jatilaba from Brebes. Cultivar MC4 was used in Trials P and Q. Seeds were broadcasted in a seed bed and, after emergence, seedlings were potted in 4 cm ϕ banana-leaf pots and in 6½ cm ϕ plastic bags in trials in Indonesia and Malaysia, respectively. To prevent infection with aphid-transmitted viruses, nurseries were covered with screen except in the treatment without nursery cover in Trial Q (Table 7.2). The nursery period lasted about one month. Raised plantlets were hardened in the open 3 to 5 days before transplanting. Field preparations consisted of ploughing, liming and harrowing. In Trial G, rice straw mulch was applied in all plots. In the other field trials different mulch treatments were added (Table 7.2). Irrigation and weeding were conducted when necessary. Further information on general cultivation techniques during the trials is given in Table 7.3. Cultivation practices of Trial I and P, representing trials in Indonesia and Malaysia respectively, are described in detail.

In Trial I, ridges of about 15 cm high and 40 cm wide were prepared before planting. Plant distances between rows were 60 cm and within rows 50 cm (circa 33,300 plants/ha). N was applied as a 13:6 mixture of ammonium sulphate (21 % N) and urea (45-46 % N), K as potassium chloride (60 % K_2O), and P as triple super phosphate (46 % P_2O_5). Manure (about 17 ton/ha), P (50 kg P_2O_5/ha) and one third of the N application

Table 7.2. Experimental design of seven hot pepper trials with various experimental factors and treatments, each conducted as randomized complete block.

Trial	Replicates	Infection*	Factors	Treatments
G	4	N	Fungicide	No sprays
				Twice weekly sprays
			Nitrogen	0 kg N/ha
				150 kg N/ha
				500 kg N/ha
I	4	N	Mulch	No mulch
				Rice straw
				White plastic
			Nitrogen	0 kg N/ha
				150 kg N/ha
				500 kg N/ha
K	4	N	Mulch	No mulch
				Woven fabric
				Silvery plastic
			Nitrogen	0 kg N/ha
				150 kg N/ha
				500 kg N/ha
L	1	A	Nitrogen	0 kg N/ha
				150 kg N/ha
				300 kg N/ha
				450 kg N/ha
			Cercospora	No inoculation
				Inoculation
M	2	A	Nitrogen	0 kg N/ha
				150 kg N/ha
				300 kg N/ha
				450 kg N/ha
			Cercospora	No inoculation
				Inoculation
P	5	N	Mulch	No mulch
				Silvery plastic
			Nitrogen	0 kg N/ha
				150 kg N/ha
				300 kg N/ha
				450 kg N/ha
Q	6	N	Nursery	No cover
				Screen cover
			Mulch	No mulch
				Silvery plastic
			Nitrogen	200 kg N/ha
				300 kg N/ha

*N = Natural infection; A = Artificial infection.

rate were applied in the plant holes, before planting. One and two months after planting, N (twice one third of the N application rate) and K (twice 30 kg K_2O/ha) were applied as side-dressings between plants, in the plant rows. The granular insecticide carbofuran (2

Table 7.3. Cultural techniques, applied in seven hot pepper nitrogen trials, among which cultivar choice, nursery period (days), number of plants per plot, plot size (m^2), and number of chemical pesticide applications.

Trial	Cultivar	Nursery period (days)	# Plants per plot	Plot size (m^2)	Chemical pesticides
G	Tit Paris	28	50	3.0*5.0	32 * Fungicide (in control) 32 * Insecticide
I	Tit Paris	29	42	3.6*3.5	19 * Fungicide 22 * Insecticide
K	Jatilaba	31	42	3.6*3.5	16 * Insecticide
L	Jatilaba	14	6	0.5*0.8	1 * Insecticide
M	Jatilaba	30	3	0.5*0.8	2 * Insecticide
P	MC4	50	60	6.0*6.0	5 * Acaricide
Q	MC4	44	60	6.0*6.0	5 * Acaricide 3 * Fungicide

kg/ha) was applied to the plant holes before planting. The local spray schedule for the control of pests and diseases was adopted. Insecticides (chlorfluazuron, mercaptodimethur) and fungicides (maneb, mancozeb, captafol) were sprayed weekly from transplanting onward.

In Trial P, ridges of about 20 cm high and 75 cm wide were prepared before planting. Plant distances were 100 cm between, and 60 cm within rows (circa 16,700 plants/ha). N was applied as ammonium nitrate (35 % N), K as potassium chloride, and P as triple super phosphate. Before planting, micro-nutrients (30 kg Fe, 20 kg Cu, 20 kg Bo, 10 kg Zi and 15 kg Mn/ha), one-third of the N application rate, one-third of the K (total application rate 175 kg K_2O/ha), and all P (50 kg P_2O_5) were applied on the plant beds. The granular insecticide carbofuran (1 kg/ha) was applied to the plant holes before planting. The remainder of the N and K was applied in equal parts as side-dressings one and two months after planting. Pesticide applications were minimized to 5 acaricide (dicofol) sprays. To control caterpillars, *Bacillus thuringiensis* was applied 5 times.

Growth chamber experiments. The two growth chamber experiments were two-factor trials with the factors N (application rates representing 0, 150, 300 and 450 kg N/ha) and disease (inoculation with *Cercospora* leaf spot and control). Trial L was a non-replicated trial with six plants per tray (i.e. experimental unit). Trial M consisted of two replications and three plants per tray. The same cultivar Jatilaba as in Trial K was used. Two to four weeks old seedlings were planted in 1.7 l pots (one plant per pot). Calcium ammonium nitrate (27 % N), was applied in three equal portions, directly after transplanting, and one and two months after planting. Water was supplied regularly. There were three inoculations, with four weeks intervals, starting one month (Trial L) or one week (Trial M) after planting. The inoculations were conducted with spore suspensions (10^6 spores/l) of *Cercospora*, obtained from sporulating leaves. After inoculation the relative humidity was kept at saturation level for one week. To control thrips, one application with methiocarb was carried out in Trial L and two applications in Trial M.

Observations

Field trials. In Table 7.4, observed responses are listed per trial. Young full-grown leaves at second youngest nodes and young ripening (about half-red and half-green) fruits were sampled several times at random for analyses of N, P and K levels. Nutrient content and pH of the soil were determined after final harvest in soil samples taken in the plant rows (4 to 8 probes per plot) until 15 to 20 cm depth.

The establishment of the crop was recorded per plot as the complement of the total number of replacements until 14 days after planting, divided by the total number of plants. Observations on crop growth consisted of regularly measuring plant height and counting branches on 10 plants per plot, chosen at random and marked. Crop development was determined through regularly counting plants with at least one fruit of

Table 7.4. Responses of hot pepper nutrient levels, crop health and performance, measured during seven nitrogen trials.

Trial	Nutrient levels	Crop health	Crop performance
G	Soil pH, N, P, K, C	Anthracnose fruit rot	Plant height
			Branching
I	Soil pH, N, P, K, C	Oriental fruit fly	Establishment
	Leaves N, P, K	Thrips	Branching
		Viruses	Plant height
			Fruiting
K	Soil pH, N, P, K	Anthracnose fruit rot	Establishment
	Leaves N, P, K	*Cercospora* leaf spot	Branching
	Fruits N, P, K	Oriental fruit fly	Plant height
		Viruses	Fruiting
L	Leaves N	*Cercospora* leaf spot	Leaves/plant
M	-	*Cercospora* leaf spot	Leaves/plant
P	Soil pH, N, P, K, C	Anthracnose fruit rot	Establishment
	Leaves N, P, K	Blossom mould	Plant height
	Fruits N, P, K	*Cercospora* leaf spot	Fruiting
		Oriental fruit fly	
		Thrips	
		Viruses	
		Yellow tea mite	
Q	Leaves N, P, K	Anthracnose fruit rot	Establishment
	Fruits N, P, K	Blossom mould	Plant height
		Cercospora leaf spot	Fruiting
		Oriental fruit fly	
		Thrips	
		Viruses	
		Yellow tea mite	

- = Not measured.

more than 1 cm length, that were divided by the total number of plants, per plot.

Crop health was observed by monitoring pests and diseases. The proportion fruit loss due to anthracnose fruit rot was assessed by dividing the accumulated number of fruits infected by anthracnose fruit rot by the total number of harvested fruits. The proportion fruit loss due to oriental fruit fly was assessed likewise. Incidences of blossom mould (*Choanephora cucurbitarum* (Berkeley & Ravenel) Thaxter), *Cercospora* leaf spot and viruses were observed per plot by counting numbers of plants with symptoms of every disease and dividing these numbers by the total number of plants. Thrips and yellow tea mite incidences were observed in a similar way, by counting numbers of plants with typical feeding injury symptoms on young leaves. Symptoms were described in Chapter 3. In the case of blossom mould, diseased plant parts were removed after determination of disease incidence, as a control method. Severity of *Cercospora* leaf spot and thrips injury were monitored by using field keys from 0 to 5 (Chapter 3).

The healthy yield was measured as fresh weight of ripe, healthy fruits per plot, accumulated over all harvest dates. The average fruit weight per plot was calculated as the healthy yield, divided by the total number of healthy fruits. The proportion of healthy fruits was calculated from the accumulated number of healthy fruits, divided by the total number of fruits. The earliness of harvesting was expressed as the mid-harvest time, the day at which half of the total healthy yield was obtained.

Growth chamber experiments. Observations on plant growth were done by regularly counting leaves per plant, including aborted leaves. N levels in leaves were assessed at the termination of Trial L, on young full-grown leaves at the second youngest nodes. Disease observations consisted of successive counts of leaf spots, numbers of leaves with spots, and measurements of diameters of the five largest leaf spots per plant. Ripe fruits were harvested, counted and weighed.

Statistical procedures

Field trials. The results of the successive observations on plant height, branching and fruiting per plot were used to calculate linear ($Y=a+bX$; X = time in days after transplanting) or quadratic ($Y=a+bX+cX^2$) regression equations. The mid-fruiting time ($X_{Y=0.50}$) was calculated per plot.

The virus incidence data were transformed to logits ($Y'=\ln[Y/(1-Y)]$; Y = percentage diseased) (Van der Plank, 1963). Sequential logit values per plot were subjected to linear regression. The virus mid-value time ($X_{Y=0.50}$ in days after transplanting) was calculated per plot. The successive observations on *Cercospora* leaf spot severity were used to calculate the Area Under the Disease Progress Curve (AUDPC) for each plot (Campbell and Madden, 1990). The results of these calculations were considered as continuous variables. The AUDPC was also calculated for disease incidence data per plot on blossom mould and *Cercospora* leaf spot, per plot. The yellow tea mite incidence, and thrips incidence and severity data were transformed in the same way, resulting in 'Area Under Pest Progress Curve' (AUPPC) figures per plot.

All numerical data and the results of processed data, such as regression parameters of linear and non-linear equations, mid-value times, AUDPC's and AUPPC's per plot were analyzed by means of Analysis Of Variance (ANOVA). Whenever significant ($P<0.05$) differences were encountered, the treatment means were separated by use of a Least Significant Difference (LSD) test. Results of nutrient analyses were expressed in mmol/kg dry weight. After statistical analyses, these figures were recalculated in percentages for easy reading.

The data sets of Trials P and Q with variables of crop performance (plant height, mid-fruiting time), crop health (anthracnose fruit rot, blossom mould, *Cercospora* leaf spot, oriental fruit fly, thrips, yellow tea mite, viruses) and crop production (healthy yield, fruit weight, proportion of healthy fruits, mid-harvest time) were used to calculate coefficients of linear correlation with nutrient levels in leaves and fruits.

Growth chamber trials. For analyses of the repeatedly observed number of leaf spots per plant during the trials, the AUDPC was calculated per experimental unit. The same procedure was followed for the number of leaves per plant ('Area Under the Leaves Progress Curve' (AULPC)). Linear and multiple regression equations of leaf spots AUDPC and of AULPC on N application rate were calculated. Linear regression on the N application rate was also performed with N levels in leaves, total numbers of aborted leaves, maximum size of leaf spots and yield. Differences between the infected and healthy treatments were tested for significance with Student's T-test in Trial L, and using ANOVA and LSD in Trial M.

7.3 Results

Field trials

Nutrient analysis. The soil analyses after the trials showed that in Trials G and I, the pH-H_2O was significantly lower in the 500 kg N/ha treatment compared to the other treatments. There were no consistent effects on soil N, P, K and C levels.

Analyses of the leaf material showed that raised application rates of N caused significant increases in N levels of leaves in Trials K, L, P and Q and of fruits in Trials P and Q (Table 7.5). In Trial P, P and K levels in the 150, 300 and 450 kg N/ha treatments were significantly lower than in the 0 kg N/ha treatment (Table 7.6). There were no effects on P in Trials I, K and Q. In Trial K, K was significantly higher in leaves in the 500 kg N/ha treatment. In Trials I and Q, there were no effects on K in leaves. There were no significant effects on P or K levels in fruits.

Table 7.5. Leaf and fruit nitrogen levels (N in % of dry weight), measured in different hot pepper nitrogen trials. Leaves were sampled once (Trial L), three times (Trials I and K) or six times (Trials P and Q). Fruits were sampled once (Trial P) or twice (Trials K and Q). Separation of means by LSD (P<0.05).

Trial	I	K		L	P		Q	
Leaves								
0 kg N/ha	4.7	5.2	c	2.0	5.5	c	-	
150 kg N/ha	4.7	5.5	b	2.8	5.8	bc	-	
200 kg N/ha	-	-		-	-		5.7	b
300 kg N/ha	-	-		3.5	6.0	ab	5.8	a
450 kg N/ha	-	-		3.9	6.1	a	-	
500 kg N/ha	4.8	5.6	ab	-	-		-	
$LSD_{0.05}$	-	0.3		N.a.	0.3		0.1	
Fruits								
0 kg N/ha	-	3.3		-	2.8	c	-	
150 kg N/ha	-	3.4		-	3.0	b	-	
200 kg N/ha	-	-		-	-		2.7	b
300 kg N/ha	-	-		-	3.1	b	2.8	a
450 kg N/ha	-	-		-	3.2	a	-	
500 kg N/ha	-	3.4		-	-		-	
$LSD_{0.05}$	-	-		-	0.1		0.1	

N.a. = $LSD_{0.05}$ not applicable; Linear correlation of N levels in leaves with N application rate significant.
- = Not measured.

Table 7.6. Average levels of phosphorus and potassium (P and K in % of dry weight) in hot pepper leaves, sampled six times during nitrogen Trial P. Separation of means by LSD (P<0.05).

	Phosphorus		Potassium	
Nitrogen application rate				
0 kg N/ha	0.50	a	3.71	a
150 kg N/ha	0.43	b	3.41	bcd
300 kg N/ha	0.41	b	3.35	cd
450 kg N/ha	0.40	b	3.17	d
$LSD_{0.05}$	0.04		0.23	

Crop performance. In Trial G, plants were significantly taller in the 150 and 500 kg N/ha than in the 0 kg N/ha treatment (Figure 7.1). In Trials G and K, branching was significantly faster in the 150 and 500 kg N/ha than in the 0 kg N/ha treatment. There were no significant N effects on crop establishment or on mid-fruiting time.

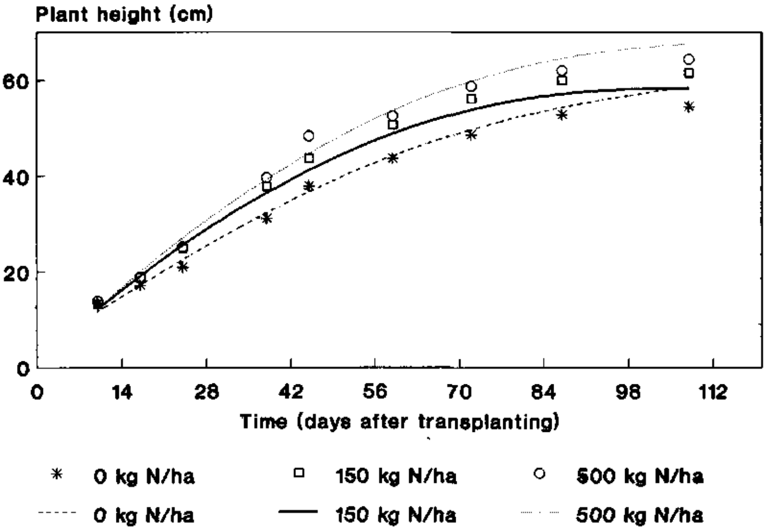

Figure 7.1. Trial G. Observed and estimated values of hot pepper plant height in field plots, fertilized with 0, 150 or 500 kg N/ha (Y = Plant height in cm; X = Time in days after transplanting).

$Y_{0\ kg\ N/ha} = 2.5 + 0.95{*}X - 0.004{*}X^2$ ($r^2 = 0.93$)

$Y_{150\ kg\ N/ha} = 1.0 + 1.18{*}X - 0.006{*}X^2$ ($r^2 = 0.94$)

$Y_{500\ kg\ N/ha} = 0.3 + 1.27{*}X - 0.006{*}X^2$ ($r^2 = 0.95$)

Crop health. In Trial P, higher N application rates significantly aggravated fruit loss due to anthracnose fruit rot (Table 7.7). In other trials there were no effects. In Trial K, incidence and severity AUDPC's of *Cercospora* leaf spot were both significantly higher in the 500 kg N/ha treatment, than in the 0 and 150 kg N/ha treatments (Figure 7.2). There were no N application rate effects on *Cercospora* leaf spot incidence in other trials. The loss of fruits due to oriental fruit fly was below 5 % in most trials. In Trial K, however, the loss ranged from 10 to 20 % and a significant N effect was found, as the 150 and 500 kg N/ha resulted in significantly higher percentages fruit loss than the 0 kg N/ha treatment (Table 7.7).

The blossom mould AUDPC and virus mid-value times were not significantly affected by N. The thrips severity and incidence AUPPC's and the yellow tea mite AUPPC were not significantly influenced by N application rate.

Table 7.7. Percentage of harvested fruits injured by anthracnose fruit rot or oriental fruit fly (%), observed in different hot pepper nitrogen trials. Separation of means by LSD (P<0.05).

Trial	G	I	K	P	Q
Anthracnose fruit rot					
0 kg N/ha	12	-	61	17 c	-
150 kg N/ha	13	-	63	26 b	-
200 kg N/ha	-	-	-	-	19
300 kg N/ha	-	-	-	33 a	21
450 kg N/ha	-	-	-	31 ab	-
500 kg N/ha	14	-	64	-	-
$LSD_{0.05}$	-	-	-	6	-
Oriental fruit fly					
0 kg N/ha	-	3	11 b	1	-
150 kg N/ha	-	3	16 a	1	-
200 kg N/ha	-	-	-	-	1
300 kg N/ha	-	-	-	1	1
450 kg N/ha	-	-	-	1	-
500 kg N/ha	-	2	19 a	-	-
$LSD_{0.05}$	-	-	4	-	-

- = Not measured.

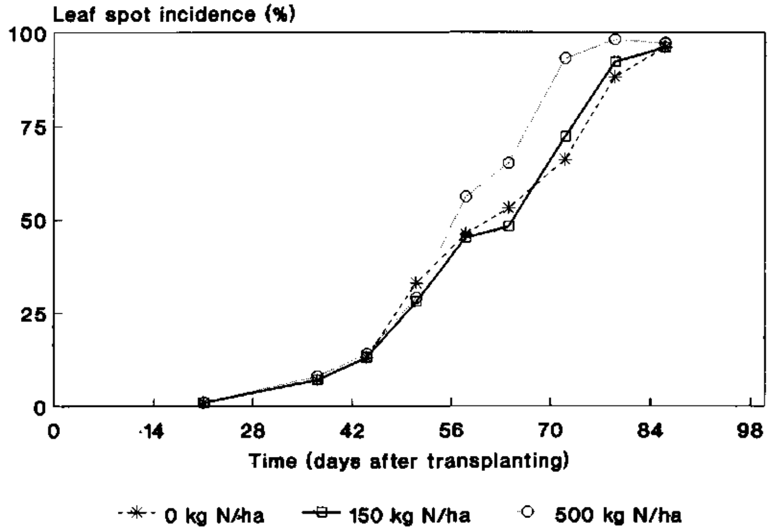

Figure 7.2. Trial K. Observed progress of *Cercospora* leaf spot incidence in hot pepper field plots, fertilized with 0, 150 or 500 kg N/ha, during time in days after transplanting.

Crop production. The harvest of Trial K was partly lost due to non-technical problems and the healthy yield is not reported. N effects on healthy yield were found in Trials G, P and Q (Table 7.8). In Trials G and P, the 150 kg N/ha fertilized plots produced the highest healthy yield. In Trial Q however, the 300 kg N/ha treatment yielded best. The proportion of healthy fruits was influenced by N application rate in Trials K and P (Table 7.8). The 0 kg N/ha treatment yielded a significantly higher proportion of healthy fruits than the other treatments. There were no N effects on mean fruit weight or on harvest mid-value time.

Table 7.8. Variables of crop production in different hot pepper nitrogen trials. Healthy yield is expressed as total weight of healthy fruits (t/ha) and percentage healthy fruits is derived from the number of healthy and the total number of fruits (%). Separation of means by LSD (P<0.05).

Trial	G		I	K		P		Q	
Healthy yield									
0 kg N/ha	2.3	b	2.8	-		2.7	b	-	
150 kg N/ha	3.4	a	3.2	-		4.8	a	-	
200 kg N/ha	-		-	-		-		5.5	b
300 kg N/ha	-		-	-		3.4	b	6.6	a
450 kg N/ha	-		-	-		3.5	b	-	
500 kg N/ha	3.5	a	3.0	-		-		-	
$LSD_{0.05}$	0.5		-	-		1.1		0.9	
% Healthy fruits									
0 kg N/ha	77		96	29	a	78	a	-	
150 kg N/ha	75		96	21	b	68	b	-	
200 kg N/ha	-		-	-		-		77	
300 kg N/ha	-		-	-		61	c	76	
450 kg N/ha	-		-	-		62	c	-	
500 kg N/ha	75		97	19	b	-		-	
$LSD_{0.05}$	-		-	5		6		-	

- = Not measured.

Crop nutrient levels and crop performance, health and production (Trials P and Q)

Table 7.9 gives the significant coefficients of linear correlation between nutrient levels in plant tissue and variables of crop performance, crop health and crop production over all plots per trial in the Trials P and Q. In Trial P, plant height was positively correlated with N, and negatively with P and K levels in leaves. Mid-fruiting times were positively correlated with P levels in leaves and negatively correlated with N levels in fruits in both trials.

The fruit loss due to anthracnose fruit rot was positively correlated with P levels in leaves and fruits in Trial Q. The blossom mould AUDPC was negatively correlated, while the *Cercospora* leaf spot AUDPC was positively correlated with N levels in leaves in both

Table 7.9. Coefficients of linear correlation ($P<0.05$) between nitrogen, phosphorus and potassium levels (N, P, K in % of dry weight) in hot pepper leaves and fruits, and parameters of crop performance, crop health and crop production in Trials P and Q. Parameters of crop performance are plant height (growth rate in cm/day) and mid-fruiting time (days after planting). Parameters of crop health are anthracnose fruit rot (% infected fruits), blossom mould (AUDPC in proportion.days), *Cercospora* leaf spot (AUDPC in proportion.days), oriental fruit fly (% injured fruits), thrips (AUPPC in proportion.days), yellow tea mite (AUPPC in proportion.days) and viruses (mid-value time in days after transplanting). Parameters of crop production are healthy yield (t/ha), mean fruit weight (g/healthy fruit), percentage healthy fruits (%) and mid-harvest time (days after transplanting).

Plant part	Leaves						Fruits					
Nutrient	Nitrogen		Phosphorus		Potassium		Nitrogen		Phosphorus		Potassium	
Trial	P	Q	P	Q	P	Q	P	Q	P	Q	P	Q
Crop performance												
Plant height	0.37	ns	-0.59	ns	-0.43	ns	0.42	ns	ns	ns	ns	ns
Mid-fruiting time	ns	-0.49	0.72	0.56	ns	ns	-0.42	-0.45	0.36	ns	ns	ns
Crop health												
Anthracnose fruit rot	ns	ns	ns	0.36	ns	ns	ns	ns	ns	0.40	ns	ns
Blossom mould	-0.38	-0.35	ns	ns	ns	ns	ns	-0.58	ns	-0.36	ns	-0.37
Cercospora leaf spot	0.35	0.40	ns	ns	ns	ns	0.38	ns	ns	ns	ns	ns
Oriental fruit fly	ns	-	ns	-	ns	-	ns	-	ns	-	ns	-
Thrips	ns	-0.36	0.66	0.71	ns	ns	ns	-0.47	0.45	0.44	ns	ns
Yellow tea mite	ns	ns	ns	0.34	ns	ns	ns	ns	0.39	ns	ns	ns
Viruses	ns	ns	-0.44	-0.45	ns	ns	ns	0.72	-0.37	ns	ns	ns
Crop production												
Healthy yield	ns	ns	-0.59	-0.75	-0.39	ns	0.40	ns	-0.40	-0.62	ns	ns
Fruit weight	ns	0.43	ns	-0.40	ns	ns	ns	0.68	ns	ns	-0.39	ns
% Healthy fruits	ns	ns	ns	-0.35	ns	ns	ns	ns	ns	-0.39	ns	ns
Mid-harvest time	ns	-0.59	0.60	ns	0.43	ns	ns	-0.46	0.38	ns	ns	ns

ns = Not significant.
- = Not determined.

trials. The thrips AUPPC incidence showed to be positively correlated with P levels in leaves and fruits in both trials and negatively correlated with N levels in leaves and fruits in Trial Q. Virus mid-value times were negatively correlated with P levels in leaves in both trials.

Healthy yield was negatively correlated with P levels in leaves and fruits in both trials. Fruit weight was positively correlated with N levels in leaves and fruits in Trial Q. The proportion of healthy fruits was negatively correlated with P levels in leaves and fruits in Trial Q. Mid-harvest time was negatively correlated with N and positively with P levels in leaves and fruits in Trials Q and P, respectively.

Growth chamber experiments

In Trial L, N levels in leaves were positively correlated with N application rates (Table 7.5).

The AULPC (leaves) increased significantly in Trial L, non-significantly in Trial M, as N application increased (Table 7.10). In both trials, the total number of aborted leaves decreased significantly when N increased. Leaf abortion in diseased plants started significantly earlier than in healthy plants in Trial L, and total leaf abortion in diseased plants was significantly higher than in healthy plants in Trial M.

Table 7.10. Effects of nitrogen on plants, inoculated with *Cercospora* leaf spot in two growth chamber trials, measured as the number of leaves per plant (AULPC in proportion.days), the number of leaves with leaf spots (AUDPC in proportion.days) and the maximum leaf spot size (cm).

N rate \ Trial	L	M
Number of leaves		
0 kg N/ha	3,936	16,769
150 kg N/ha	6,434	28,322
300 kg N/ha	12,354	21,611
450 kg N/ha	15,074	25,650
$LSD_{0.05}$	N.a.	-
Number of leaves with spots		
0 kg N/ha	-	275 b
150 kg N/ha	-	329 b
300 kg N/ha	-	480 a
450 kg N/ha	-	350 b
$LSD_{0.05}$	-	78
Leaf spot size		
0 kg N/ha	1.3	0.7 b
150 kg N/ha	1.7	0.9 a
300 kg N/ha	2.1	0.9 a
450 kg N/ha	2.5	0.9 a
$LSD_{0.05}$	N.a.	0.1

N.a. = $LSD_{0.05}$ not applicable; Linear correlation with N application rate significant.
- = Not measured.

The AUDPC for the number of leaf spots per plant increased significantly with N application rate. Data obtained in Trial L were fitted by a linear, data in Trial M by a multiple regression equation (Figure 7.3). In Trial M, the AUDPC of the number of leaves with leaf spots was significantly higher in the 300 kg N/ha treatment than in the others (Table 7.10). The leaf spot size significantly increased with N application rate in both trials (Table 7.10).

In both trials, the yields were poor, probably due to lack of nutrients other than N. There were no effects of *Cercospora* leaf spot on the crop production. The total number of harvested fruits and the fruit weights were significantly correlated with N application rate in both trials.

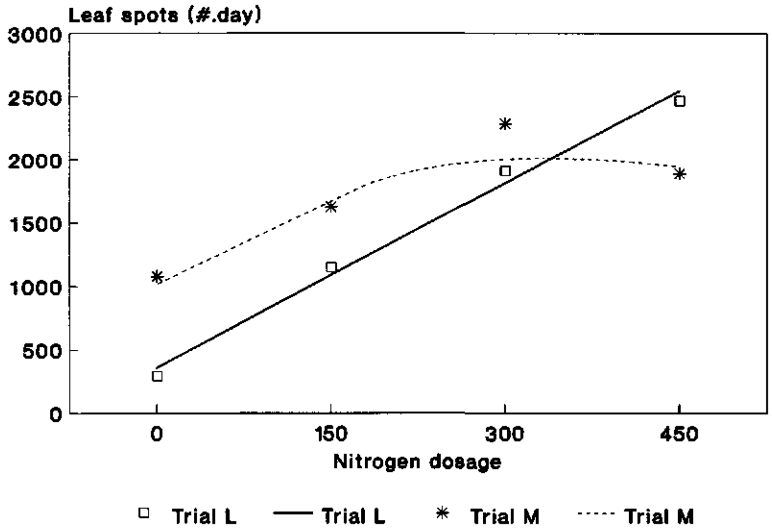

Figure 7.3. Trials L and M. Observed values and estimated nitrogen dose-response graphs of the Area Under the Disease Progress Curve (AUDPC) of the number of leaf spots per hot pepper plant, caused by artificial infection with *Cercospora* leaf spot (Y = AUDPC in days; N = Nitrogen application rate in kg N/ha) in pot experiments under growth chamber conditions.

$Y_{Trial\ L} = 359 + 4.86*N$ ($r = 0.99$) $n = 18$

$Y_{Trial\ M} = 1018 + 6.78*N - 0.011*N^2$ ($r^2 = 0.82$) $n = 13$

7.4 Discussion and conclusions

Experimental results were not consistent over all trials. The variability between trials was caused by differences in environment, weather, plant material, maintenance of trials, and so on. Conclusions are based on significant effects in one or more trials.

Nutrient balance

Adequate nutrient levels for *Capsicum* reportedly are: 3.0-4.5 % N, 0.3-0.7 % P and 4.0-5.4 % K at mid-growth, 2.9-4.6 % N, 0.3-0.5 % P and 2.6-5.5 % K at early fruit stages, measured in youngest mature leaves (Reuter and Robinson, 1986). Comparing these values with Table 7.5, it can be concluded that N levels in leaves were high in all field trials. In growth chamber Trial L, N levels were measured after final harvest and found to be adequate in the 300 and 450 kg N/ha treatments only. Table 7.6 shows that in Trial P, P levels were adequate, but K was insufficient at mid-growth stage. The plant nutrition appeared unbalanced, though correct balancing of N and K is known to be important in relation to crop health (Perrenoud, 1977).

Effects of nitrogen application rates

Crop performance. Generally, plant growth was stimulated by N fertilization. Plant height was promoted by N in Trial G, and a positive correlation was found with N levels in leaves and fruits in Trial P. Branching was enhanced in two out of three field trials and the number of leaves per plant was increased in one out of two growth chamber trials.

Effects of N application rates on mid-fruiting times were not significant. A negative correlation was found with N levels in fruits and a positive correlation with P levels in leaves in the Trials P and Q. In Trial P, P levels in leaves were reduced due to fertilization with N. The correlations lead to the suggestion that shorter mid-fruiting times may be expected, when N levels in fruits are high and P levels in leaves are low. The experimental results, however, lead to the conclusion that mid-fruiting times were not influenced by N application rates.

Crop health. In Trial P, fruits were more susceptible to anthracnose fruit rot when plants had been fertilized with increasing application rates of N, conform Asandhi and Koestoni (1989). In Trial Q, a positive correlation was found between P levels in leaves and fruits and anthracnose fruit rot incidence. The physiological background for these N application rate effects is yet unknown.

There were no N application rate effects on blossom mould, but negative correlations with N levels in leaves were found in the Trials P and Q, meaning that N controlled blossom mould. Perhaps there were unrecognized effects of N application rates, due to the sanitation method of removing infected plant parts.

The N application rate effect on *Cercospora* leaf spot in field Trial K were confirmed by the growth chamber studies (Trials L and M). The effect of N application rates on the incidence in Trial K was consistent with the positive correlation with N levels in leaves in the Trials P and Q. It is concluded that N promoted the incidence and severity of

Cercospora leaf spot.

The N application rate effect on oriental fruit fly in Trial K, could have been caused by a N effect on fruit size, which was not measured. A large fruit size was found attractive to *Bactrocera oleae* (Katsoyannos, 1989). The effect in Trial K was incidental and its generalisation value is questionable.

The thrips incidence and severity appeared not to be significantly influenced by N application rates, in spite of Lewis' anticipation (1973) that a high amount of N compounds in leaf tissue would benefit thrips. On the contrary, correlations with N levels in leaves and fruits were negative in Trial Q. Positive correlations with P levels in leaves and fruits were found, that cannot be explained by N application rate effects only. Further research is required to investigate this phenomenon.

Virus epidemics were not affected by variable N application rates. The correlation with P levels of leaves in the Trials P and Q cannot be explained by nitrogen application rate effects only.

There were no N application rate effects on yellow tea mite, possibly due to interference by chemical control.

Crop production. Yields were improved by N fertilization. In Trials I and P, 150 kg N/ha gave the highest healthy yield, while in Trial Q, 300 kg N/ha produced the best healthy yield. Trial G showed that a high application rate of N (500 kg N/ha) did not lead to a significantly better production, compared to moderate rates of N. Healthy yield was not correlated with N levels in leaves, but negative correlations with P levels in leaves and fruits were found in Trials P and Q. These effects are not understood and need further investigation. In Trial Q, fruit weight was positively correlated with N levels. In other trials, fruit weight was not influenced by N, although higher N levels in fruits were detected. The proportion of healthy fruits was reduced by increasing N rates in Trials K and P, due to effects on anthracnose fruit rot and oriental fruit fly. The mid-harvest time was not significantly influenced by N application rates, even though a negative correlation with N levels in leaves and fruits was found in Trial Q.

Mulching

Effects of mulches on plant nutrient levels were reported in Chapter 5. Plastic mulches increased N and reduced P levels in leaves and fruits, leading to the conclusion that mulching improved N uptake. However, significant interactions between mulch and N treatments were rare.

Feasibility of recommended nitrogen application rates

In a preliminary on-farm experiment with 10 farmers in the hot pepper production area of Brebes (Central Java), tentatively recommended fertilizer rates of 180 kg N, 60 kg P_2O_5

and 60 kg K_2O/ha were compared with farmers' standard fertilizer practices. Standard fertilizer practices varied per farmer from 152 to 1190 kg N, from 0 to 308 kg P_2O_5, and from 0 to 363 kg K_2O/ha. As a result of the experiment, no differences in crop production were found. The result implies that, when recommended fertilizer rates were applied, revenues were probably higher as costs of fertilizer inputs for most farmers were reduced. However, yields varied extremely, from 3 to 29 t/ha, between farmers. It seemed that in the cases with high yields, harvesting periods were prolonged and farmers applied larger amounts of fertilizers. In these cases, the recommended fertilizer treatment lagged behind in production. An adaptation of the recommended fertilizer rates was proposed in case of long harvesting periods.

Nitrogen fertilizing as a component of ICM

N application improved crop growth. Production of healthy fruits was improved by moderate application rates of N (150 kg N/ha). Variable effects of N application rates on anthracnose fruit rot, blossom mould, *Cercospora* leaf spot and oriental fruit fly were found. The theoretical background of these effects remained to be unravelled. Engelhard (1989) stated, that physiological processes associated with nutrition may be more or less understood, but knowledge on direct linkages of biochemical and physiological processes with disease is rather incomplete. Nevertheless, experimental results can be used for an ICM programme in order to reduce excessive use of fertilizers and to improve crop performance, crop health and crop production. Effects of P, K and other elements are not yet known. Follow-up fertilizer experiments are needed to find appropriate and balanced application rates of various nutrients.

Chapter 8

General discussion

Evaluation of components of integrated crop management of hot pepper (*Capsicum* spp.) in various production situations

Abstract: In order to analyze 16 integrated crop management trials, with various experimental designs and conducted in different production situations, results were analyzed using the descriptive statistical method of correspondence analysis. Cultural practices, such as nursery cover, seed bed, nursery period, mulching, nitrogen fertilizing and type of cultivar were arranged in contingency tables with virus infection and with healthy yield. Variables of crop health were also combined with healthy yield. Low values for virus infection were closely associated with the use of plastic mulch, and high virus with high nitrogen application rates. Increase of nitrogen was associated with increase of yield until moderate applications of nitrogen. Low yield was associated with absence of plastic mulching. Yield was strongly associated with virus infection. It was confirmed that cultural practices could benefit crop production through, among others, improvement of crop health. Type of cultivar or location did not influence effects on yield by mulch, nitrogen, nursery period and seed bed.

8.1 Introduction

During research on integrated crop management (ICM) of hot pepper (*Capsicum* spp.) in tropical lowlands, effects of various cultural techniques were tested in factorial field trials at different locations in lowlands of Indonesia and Malaysia. The research hypothesis, introduced in Chapter 1, was that specific cultural techniques may be components of ICM if they improve crop performance, crop health and crop production. Descriptions of cultural techniques employed by farmers in different production areas in Indonesia and of parameters of crop health were given in the Chapters 2 and 3, respectively. Factors tested were plant raising (Chapter 4), mulching (Chapters 5 and 6) and nitrogen fertilizing (Chapter 7). Each of the 16 field experiments was analyzed using Analysis of Variance (ANOVA). The results of the individual trials were not always consistent, due to variation in environment, weather, cultivar, occurrence of pests and diseases, maintenance of trials, and so on. A synoptic evaluation of all trials in different 'production situations' (de Wit, 1982) was desired. To that purpose, the factorial experiments were analyzed by means of correspondence analysis, developed by Benzécri (1973), and introduced to the study of 'multiple pathosystems' (Zadoks, 1990) by Savary *et al.* (1988) and Savary and Zadoks (1992). Correspondence analysis is a multivariate, non-parametric statistical analysis for the description of associations between variables, based on contingency tables and chi-square tests. Individual variables are categorized into classes. Correspondence analysis enables the association of the position of each class respective to axes, of paths of increasing class values, and of the position of each class and/or path respective to that of other variables. In this evaluation, correspondence analysis is used to compare crop responses to components of ICM of hot pepper over 16 field trials performed in a variety of production situations.

8.2 Methodology

The series of 16 field trials (Table 8.1), conducted over the period from 1989 to 1992 in Indonesia and from 1993 to 1994 in Malaysia added up to a total of 494 individual plots, used to construct a database. Trials A-K and O-R are described in the Chapters 4-7. Trials A-K and O-R were performed under various conditions, and plot sizes were not equal for all trials. Trial N was a plot size trial, with small (9 m^2), medium (19 m^2) and large (36 m^2) plots, designed as a randomized complete block and conducted in 4 replications. Observations were statistically analyzed as in Trials A-K and O-R.

Table 8.1. Hot pepper field trials, locations, periods of execution, experimental factors and number of experimental plots.

Trial	Location*	Period	Factors	# Plots
A.	Brebes	Aug'89-Jan'90	Nursery cover Seed bed	18
B.	Brebes	Dec'89-Mar'90	Mulch Plant density	24
C.	Subang	Jun'90-Sep'90	Mulch	20
D.	Tegal	Jul'90-Nov'90	Mulch	20
E.	Subang	Aug'90-Jan'91	Nursery cover Seed bed	60
F.	Subang	Feb'91-May'91	Mulch	20
G.	Subang	Feb'91-Jun'91	Nitrogen Fungicide	24
H.	Subang	Mar'91-Jul'91	Nursery cover Seed bed Nursery period	54
I.	Subang	Aug'91-Dec'91	Mulch Nitrogen	36
J.	Subang	Nov'91-Apr'92	Nursery cover Seed bed Nursery period	48
K.	Subang	Jan'92-May'92	Mulch Nitrogen	36
N.	Klang	Apr'93-Nov'93	Plot size	12
O.	Klang	May'93-Dec'93	Nursery cover Nursery period	30
P.	Klang	Aug'93-Dec'93	Mulch Nitrogen	32
Q.	Klang	Aug'93-Jan'94	Nursery cover Mulch Nitrogen	40
R.	Klang	Sep'93-Mar'94	Nursery cover Mulch	20

*Brebes, Subang and Tegal are locations in Indonesia, Klang is a location in Malaysia.

Table 8.2. Coding, categorization and frequencies of variables used for correspondence analysis.

Code	Description*	Unit	Class	Boundaries of classes	Frequency (Absolute (%))
Ant	Anthracnose injury	% fruits	Ant1	≤ 4	138 (39 %)
			Ant2	4 - 16	101 (29 %)
			Ant3	> 16	115 (33 %)
Bed	Seed bed	-	Bed1	No pots	77 (16 %)
			Bed2	Banana pots	233 (47 %)
			Bed3	Plastic bags	184 (37 %)
Cov	Nursery cover	-	Cov1	No screen	159 (32 %)
			Cov2	Screen	335 (68 %)
Cul	Cultivar	-	Cul1	Tit Paris	324 (66 %)
			Cul2	MC4/Jatilaba	170 (34 %)
Fly	Fruit fly injury	% fruits	Fly1	≤ 1	144 (50 %)
			Fly2	1 - 10	50 (18 %)
			Fly3	> 10	92 (32 %)
Mul	Mulch	-	Mul1	No plastic	322 (65 %)
			Mul2	Plastic	172 (35 %)
Nit	Nitrogen dosage	kg N/ha	Nit1	≤ 150	80 (16 %)
			Nit2	150 - 180	168 (34 %)
			Nit3	180 - 200	136 (28 %)
			Nit4	> 200	110 (22 %)
Per	Nursery period	days	Per1	≤ 30	188 (38 %)
			Per2	30 - 34	114 (23 %)
			Per3	> 34	192 (39 %)
Rai	Monthly rain	mm	Rai1	≤ 166	174 (35 %)
			Rai2	166 - 220	152 (31 %)
			Rai3	> 220	168 (34 %)
Thr	Thrips AUPPC	%.days	Thr1	≤ 51	51 (33 %)
			Thr2	51 - 691	52 (34 %)
			Thr3	> 691	51 (33 %)
Vir(1)	Virus AUDPC	%.days	Vir1	≤ 1854	109 (33 %)
			Vir2	1854 - 3000	102 (31 %)
			Vir3	> 3000	115 (35 %)
Vir(2)	Virus AUDPC	%.days	Vir1	≤ 1684	81 (25 %)
			Vir2	1684 - 2165	82 (25 %)
			Vir3	2165 - 3482	82 (25 %)
			Vir4	> 3482	81 (25 %)
Yie	Healthy yield	t/ha	Yie1	≤ 2.5	71 (20 %)
			Yie2	2.5 - 4.0	71 (20 %)
			Yie3	4.0 - 5.3	72 (20 %)
			Yie4	5.3 - 8.6	71 (20 %)
			Yie5	> 8.6	71 (20 %)

*AUPPC = Area Under the Pest Progress Curve and AUDPC = Area Under the Disease Progress Curve in %.days, where % is the percentage of infested or diseased plants.

The variables used for correspondence analysis are listed in Table 8.2. Observation methods of individual variables are described in the Chapters 4-7. Responses were categorized in distinct classes, based upon frequencies (Table 8.2). Two-way contingency tables were composed of responses in which cells represented frequencies of occurrence of the column-row combination. Table 8.3 lists results of Pearson chi-square tests for absence of independence and of Mantel-Haenszel chi-square tests (Mantel and Haenszel, 1959) for linear association as applied to the various contingency tables.

Two-way tables with, in the columns, classes of the virus variable (Vir(2)) and, in the rows, classes of variables of cultural tactics (Cov, Per, Mul, Cul), with as supplementary row variable nitrogen dosage (Nit) were merged to Matrix I (Appendix). Similarly, Matrix II (Appendix) contained classes of the yield variable (Yie) in the columns and classes of variables of cultural tactics (Cov, Bed, Per, Mul, Nit, Cul) in the rows. Matrix III (Appendix) had classes of the yield variable (Yie) in the columns and classes of crop health variables (Vir(1), Thr, Fly, Ant) in the rows, with as supplementary row variables cultivar and rainfall (Cul, Rai). Correspondence analysis of each matrix was performed, using the statistical software package NDMS designed by M. Noirot (Savary *et al.*, 1988).

Table 8.3. Results of chi-square (χ^2) tests on absence of independence (Pearson) and linear association (Mantel-Haenszel) of two-way contingency tables, with a total of n observations (plots) per table. Matrix column and row variables are virus AUDPC (Vir), yield of healthy fruits (Yie), type of nursery cover (Cov), duration of nursery period (Per), type of mulch (Mul), amount of nitrogen fertilizer (Nit), cultivar (Cul), type of seed bed (Bed), thrips AUPPC (Thr), loss of fruits due to oriental fruit fly (Fly), loss of fruits due to anthracnose fruit rot (Ant), and average monthly rainfall (Rai). For explanation of codes see Table 8.2.

			Pearson			Mantel-Haenszel	
Column	Row	n	χ^2	df	p	χ^2	p
Matrix I							
Vir(2)	Cov	326	10	3	0.02	0	0.86
	Cul	326	85	3	0.00	29	0.00
	Mul	326	50	3	0.00	48	0.00
	Nit	326	45	9	0.00	10	0.00
	Per	326	79	6	0.00	12	0.00
Matrix II							
Yie	Bed	356	29	8	0.00	6	0.02
	Cov	356	8	4	0.11	2	0.21
	Cul	356	16	4	0.00	5	0.02
	Mul	356	97	4	0.00	96	0.00
	Nit	356	78	12	0.00	24	0.00
	Per	356	31	8	0.00	2	0.13
Matrix III							
Yie	Ant	318	30	8	0.00	18	0.00
	Cul	356	16	4	0.00	5	0.02
	Fly	250	27	8	0.00	1	0.37
	Rai	356	33	8	0.00	0	0.62
	Thr	154	28	8	0.00	5	0.03
	Vir(1)	290	115	8	0.00	81	0.00

8.3 Results

Experimental plot sizes

In Trial N, results showed no significant differences in yield of healthy fruits, yield loss due to anthracnose fruit rot and oriental fruit fly, and in incidence of thrips and viruses in relation to plot size.

Cultural practices associated with virus

Correspondence analysis of Matrix I resulted in associations between virus and variables of cultural techniques (Table 8.4 and Figure 8.1). The first and second axes accounted for 91 % of total variation (inertia 67 and 24 %, respectively). Axis 1 is mainly determined by cultivar (Cul1 opposed to Cul2) and nursery period (Per1 opposed to Per3). In fact, the variable cultivar is confounded with an unused variable (location of trial), as cultivar Tit Paris was used in Indonesia and cultivar MC4 in Malaysia. Axis 2 is determined by the variables nursery period (Per2 opposed to Per1 and Per3) and mulch

Table 8.4. Correspondence analysis of Matrix I, where axes 1 and 2 explained 67 and 24 % of total variation, respectively. Relative weight expresses the relative number of counts per class in percentage, contribution to the axes is expressed in percentages and the sign represents the position relative to zero for each axis.

		Axis 1		Axis 2	
Classes	Relative weight	Absolute contribution	Sign	Absolute contribution	Sign
Columns					
Vir1	25	10	+	63	+
Vir2	25	2	+	24	-
Vir3	25	16	+	13	-
Vir4	25	72	-	0	+
Rows					
Cov1	6	0	-	5	-
Cov2	19	0	+	2	+
Cul1	12	27	+	7	-
Cul2	13	25	-	7	+
Mul1	13	8	-	17	-
Mul2	12	8	+	18	+
Per1	8	20	+	3	+
Per2	7	1	-	30	-
Per3	10	11	-	11	+
Supplementary rows					
Nit1	0	0	+	0	-
Nit2	0	0	+	0	-
Nit3	0	0	-	0	+
Nit4	0	0	-	0	-

(Mul1 opposed to Mul2). The lines connecting Cul1 and Cul2 and Mul1 and Mul2 pass through the origin at nearly right angles, suggesting that the variables cultivar and mulch operate independently. The variable nursery cover contributes little to the total variation. The large scatter of the variable nursery period suggests some unravelled interaction with virus.

The trajectory of the variable virus AUDPC (vir) shows a curious loop, mainly

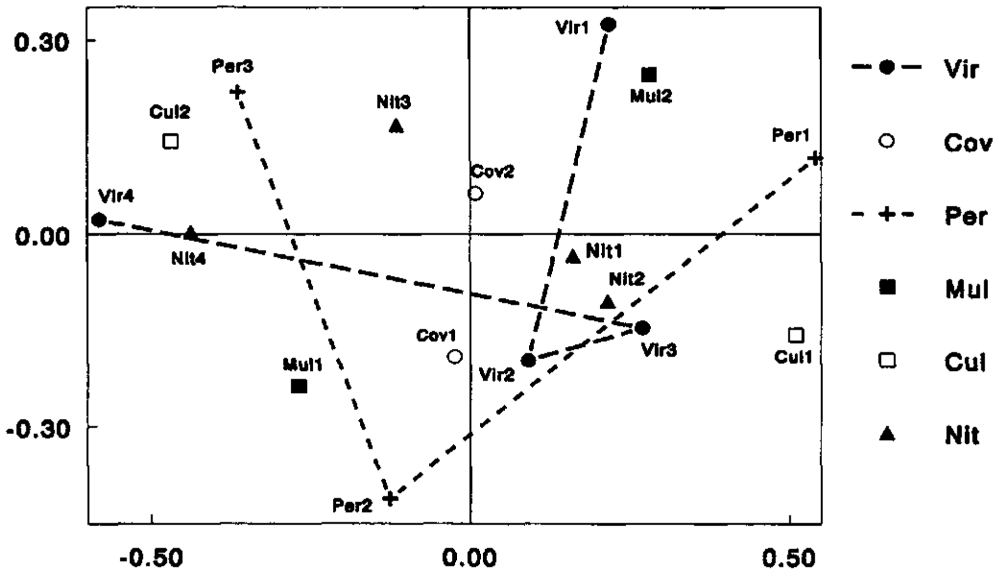

Figure 8.1. Correspondence analysis of Matrix I, with projections of classes of variables and paths of increasing levels. For explanation of codes see Table 8.2.

because the line Vir2-Vir3 is the projection of a path which in three-dimensional representation would run nearly parallel to axis 3. The same is true for the path Nit1-Nit2, but in opposite direction. The trajectories Vir2/3-Vir4 and Nit2-Nit4 run more or less parallel.

Low virus (Vir1) and plastic mulch (Mul2) are closely associated. So are high virus (Vir4) and high nitrogen (Nit4).

Cultural practices associated with yield

Correspondence analysis of Matrix II showed associations between yield and various cultural techniques (Table 8.5 and Figure 8.2). Axes 1 and 2 explain nearly all variation (inertia 61 and 33 %, respectively). Axis 1 is largely determined by the variables mulch (Mul1 opposed to Mul2), and nitrogen (Nit1 and 4 opposed to Nit3). Axis 2 is determined partly by the variable nursery period (Per2 opposed to Per3). The variable seed bed seems to contribute much to axis 2, mainly due to the outlier no pots (Bed1), but this class has negligible relative weight (1 %). Confounding of the variable seed bed with others, such as country, appears likely. Low yield (Yie2) was associated with banana leaf pots (Bed2) and cultivar Cul1, both used in Indonesia only, and high yield (Yie5) with plastic pots (Bed3) and cultivar Cul2, both mainly applied in Malaysia. As in Figure 8.1, the variables mulch and cultivar appear independent.

The curvature of the yield trajectory Yie3-Yie4-Yie5 follows the curvature of the nitrogen trajectory Nit1-Nit2-Nit3, indicating that increase of nitrogen is associated with increase of yield until moderate applications (Nit3). The trajectory Nit3-Nit4 bends back sharply, suggesting strong interaction between yield and nitrogen application rates. High application rate (Nit4) is associated with medium yields (Yie2, Yie3). Curiously, the Mantel-Haenszel chi-square for linearity is significant (Mantel-Haenszel χ^2=24; P<0.01).

Table 8.5. Correspondence analysis of Matrix II, where axes 1 and 2 explained 61 and 33 % of total variation, respectively. Relative weight expresses the relative number of counts per class in percentage, contribution to the axes is expressed in percentages and the sign represents the position relative to zero for each axis.

		Axis 1		Axis 2	
Classes	Relative weight	Absolute contribution	Sign	Absolute contribution	Sign
Columns					
Yie1	20	29	+	30	-
Yie2	20	11	+	0	+
Yie3	20	1	+	21	+
Yie4	20	6	-	25	+
Yie5	20	53	-	23	-
Rows					
Bed1	1	0	-	17	+
Bed2	8	4	+	0	-
Bed3	8	3	-	2	-
Cov1	5	0	-	4	+
Cov2	12	0	+	1	-
Cul1	10	2	+	3	+
Cul2	6	3	-	5	-
Mul1	10	23	+	2	-
Mul2	7	32	-	3	+
Nit1	3	8	+	0	+
Nit2	5	2	-	1	+
Nit3	4	14	-	17	-
Nit4	5	6	+	5	+
Per1	7	1	+	4	-
Per2	6	2	-	23	+
Per3	4	0	+	11	-

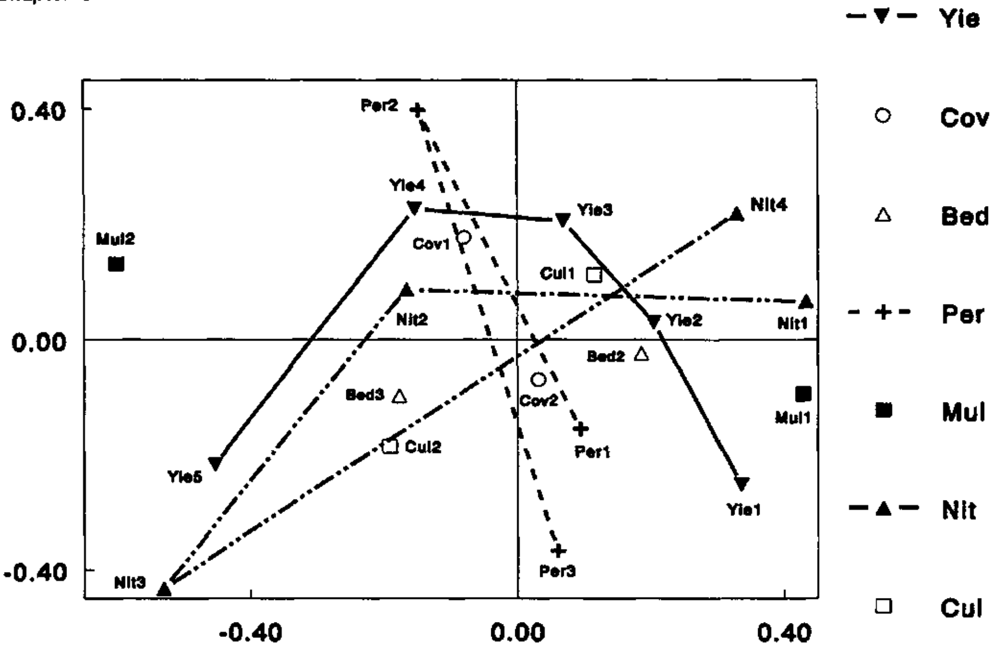

Figure 8.2. Correspondence analysis of Matrix II, with projections of classes of variables and paths of increasing levels. For explanation of codes see Table 8.2.

This is not the case for the variable nursery period, which typically shows interaction (Pearson χ^2=31; P<0.01 and Mantel-Haenszel χ^2=2; P=0.13). The nursery period trajectory runs parallel to the trajectory Yie1-Yie2-Yie3, with Per1 associated with Yie1, and Per2 associated with Yie4. The nursery cover effect is non-significant (Pearson χ^2=8; P=0.11).

Low yield (Yie1) is associated with no plastic mulch (Mul1) and high yield (Yie5) with moderately high nitrogen application rates (Nit3).

Pests and diseases associated with yield

Correspondence analysis of Matrix III demonstrated associations between yield and pests and diseases (Table 8.6 and Figure 8.3). The first and second axes explain nearly all variation (inertia 63 and 33 %, respectively). Axis 1 is largely determined by the variable virus AUDPC (Vir1 opposite to Vir3) and loss due to anthracnose fruit rot (Ant3). Axis 2 is determined by the variables loss due to oriental fruit fly (Fly3) and thrips AUPPC (Thr3). The additional variable cultivar is projected as Cul1, associated with lower yield levels, and Cul2, with higher yield levels, as expected. Rainfall shows an optimum at Rai2, Rai1 (representing dry periods) and Rai3 (representing wet periods) being somewhat associated with low yield levels (Yie1 and Yie2).

Figure 8.3 shows a strong association of yield and virus trajectories (Pearson χ^2=115; P<0.01) and high linearity (Mantel-Haenszel χ^2=81; P<0.01), explained by yield reduction due to viruses. Yield follows a curved trajectory, as in Figure 8.2, but mirrored on axis 1. The virus AUDPC path runs nearly parallel to the yield path, but in opposite direction, high yield (Yie5) being associated with low virus AUDPC (Vir1) and low yield (Yie1) with high virus AUDPC (Vir3). Associations between yield and other pests and diseases were less prominent (Pearson $\chi^2 \leq 30$; P<0.01). The variable anthracnose injury shows an association with high rainfall and moderately low yield levels (Ant3, Rai3 and Yie2). Low thrips AUPPC (Thr1) is also associated with high rainfall (Rai3). The thrips trajectory Thr1-Thr2 runs parallel to and in opposite direction of the rainfall trajectory Rai2-Rai3, in accordance with the observation that thrips infestation is reduced during rainy periods (Chapter 6, Figure 6.1). The trajectory Thr2-Thr3 is independent of rainfall.

Table 8.6. Correspondence analysis of Matrix III, where axes 1 and 2 explained 63 and 33 % of total variation, respectively. Relative weight expresses the relative number of counts per class in percentage, contribution to the axes is expressed in percentages and the sign represents the position relative to zero for each axis.

		Axis 1		Axis 2	
Classes	Relative weight	Absolute contribution	Sign	Absolute contribution	Sign
Columns					
Yie1	21	55	+	14	+
Yie2	19	4	+	5	-
Yie3	19	2	-	17	-
Yie4	21	4	-	18	-
Yie5	20	35	-	44	+
Rows					
Ant1	12	0	-	0	+
Ant2	11	1	-	1	-
Ant3	9	18	+	5	-
Fly1	14	0	-	6	+
Fly2	4	3	+	0	+
Fly3	6	0	-	24	-
Thr1	5	1	+	5	-
Thr2	5	1	-	0	-
Thr3	5	2	-	36	+
Vir1	11	30	-	2	+
Vir2	10	2	-	9	-
Vir3	8	41	+	11	+
Supplementary rows					
Cul1	0	0	+	0	-
Cul2	0	0	-	0	+
Rai1	0	0	+	0	+
Rai2	0	0	-	0	+
Rai3	0	0	+	0	-

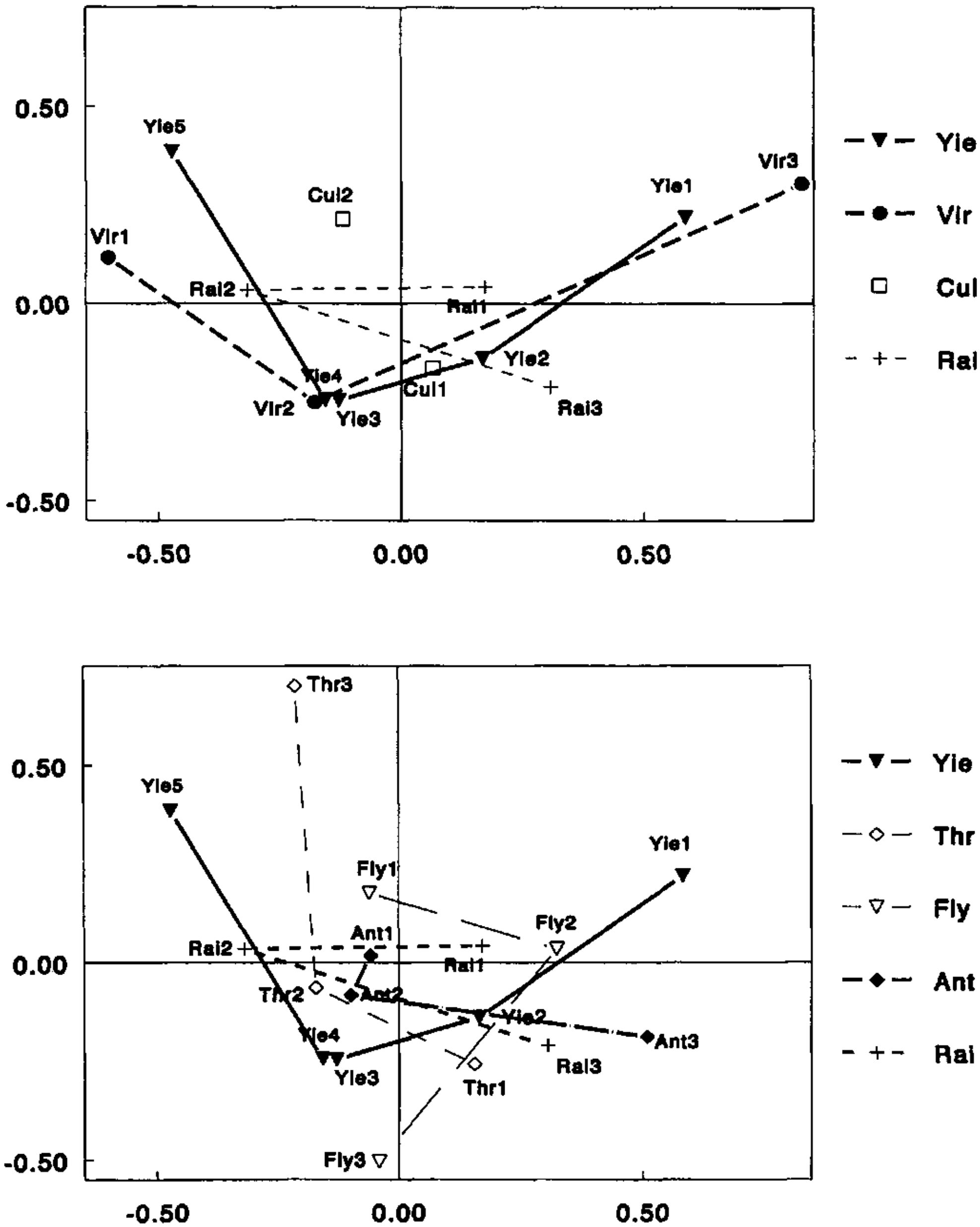

Figure 8.3. Correspondence analysis of Matrix III, with projections of classes of variables and paths of increasing levels. For explanation of codes see Table 8.2.

The oriental fruit fly trajectory follows a course more or less opposite to the thrips trajectory. Fly1-Fly2 is parallel with Rai2-Rai3 showing that oriental fruit fly damage increases during rainy periods (as reported in Chapter 3), while Fly2-Fly3 seems independent of rainfall. The rainfall trajectory shows a typical interaction, as confirmed by lack of linearity in the rainfall-yield relation (Pearson χ^2=33; P<0.01 and Mantel-Haenszel χ^2=0; P=0.62).

8.4 Synopsis of results

Overall analysis

The matrices, used for descriptive statistical analysis, represented connections between (I) cultural practices and crop health, (II) cultural practices and crop production, and (III) crop health and crop production, over a range of production situations, weather conditions, and so on. As cultivar and location are confounded, cultivar effects can be seen, at least partly, as location effects.

Analysis of Matrix I showed that cultivar and nursery period were the major factors associated with virus incidence. There is no evidence for differences in resistance to virus disease between cultivars (the issue was not tested experimentally) and cultivars were assumed to be equally susceptible to viruses. In Indonesia, virus symptoms were often camouflaged due to early infestations with thrips and/or mites, so that observers became confused. The virus observations in Malaysia were done by the author only, and symptoms seemed easy to observe. In addition, virus observations were made every fortnight in Indonesia and every week in Malaysia. The association in Figure 8.1 between long nursery period (Per3) and high virus incidence (Vir4) is in accordance with the trial results in the case of plants that were raised in open nurseries. Long nursery periods in screen-covered nurseries led to a delay of virus infection in the field (Chapter 4).

The association of mulching with virus infection is confirmed by the conclusions of mulch trials, reported in Chapter 6. The association in Figure 8.1 between increased nitrogen application and higher virus AUDPC, was not found in individual trials. It may be a typical effect of differences in production situations, high input levels being conducive to high vector levels and thus high transmission of virus, and good visibility of virus symptoms. The absence of association in Figure 8.1 between nursery cover and virus incidence in the field may be due to the low incidence of virus during the nursery phase in the trials testing aphid-proof screened versus unscreened nurseries (Chapter 4).

Analysis of Matrix II showed that yield was influenced by mulch as the single major factor, as confirmed by trial results (Chapter 5). Other effects on yield were caused by nitrogen application rate, nursery period and seed bed. The conclusion, that more than moderate application rates of nitrogen did not benefit yields (Chapter 7), is illustrated by the interactive trajectory of nitrogen in Figure 8.2. The best nitrogen application rate, in all environments, was 180-200 kg N/ha (Nit3). An optimum nursery period appeared to be 30 - 34 days (Per2 in Figure 8.2), whereas trial results showed favourable nursery periods of about 45 days (Chapter 4). Confounding with nursery cover may have occurred, as long nursery periods benefitted crop production only when nurseries were screen-covered.

The variable cultivar was not associated with yield and did not determine the axes of Figure 8.2, so that the illustrated effects of cultural tactics on yield were irrespective of cultivar (or location).

Analysis of Matrix III showed that yield was mainly associated with virus incidence. This association explains the major effect of mulch on yield in the analysis of Matrix II. Obviously, cultural practices can benefit crop production through, among others, improvement of crop health. The point is supported by the conclusion of Chapter 6, that mulching with plastic foil improved yield through, among others, delay in virus infection.

Another conclusion from individual trials, that thrips reduced yield (Chapter 6), was not confirmed by Figure 8.3. The trajectory of thrips runs opposite to the trajectory of oriental fruit fly in Figure 8.3. There may be a confounding effect of rainfall and/or other unknown factors. The association of thrips with rainfall in Figure 8.3 is confirmed by the field observation that thrips incidence is reduced during rainy periods (Chapter 3 and 6). In contrast, oriental fruit fly was more problematic indeed during rainy periods (Chapter 3). However, the projection of the extremes, Thr3 and Fly3, in Figure 8.3 could not be explained.

Anthracnose fruit rot reduced yield, especially during rainy periods (Chapter 3), as illustrated by Figure 8.3. The partial resistance of cultivar Tit Paris (Cul1) to anthracnose fruit rot (Chapter 7) is not expressed in Figure 8.3.

General conclusions

The synoptic analysis of all field trials, in addition to the individual analyses of the trials (Chapters 4-7), led to the following general conclusions on cultural practices as components of ICM. 1. Raising plant material in screen-covered nurseries increased yield, but relations with virus incidence remain to be clarified. 2. Use of potted plantlets improved crop performance but did not influence crop production. 3. The best nursery period generally was 30 to 34 days, even though in screen-covered nurseries a raising period of 1½ months was superior. 4. Plastic mulch delayed virus infection, reduced thrips injury and improved crop production. 5. Best yields were attained with nitrogen fertilization of 150 to 200 kg N/ha. 6. Of the occurring pests and diseases, virus was the most important yield determining factor. 7. Cultural practices benefitted crop production through, among others, improvement of crop health. 8. Effects on yield of the ICM components nursery period and seed bed, mulch, and nitrogen were irrespective of cultivar or location.

Implementation of ICM by hot pepper producers

In Chapter 1, the on-farm client oriented research (OFCOR) methodology was proposed as a farmer-oriented research strategy for ICM. Farmers were involved during the initiation phase of the hot pepper ICM research by way of a research-planning workshop (Chapter 1) and of surveys in production areas (Chapter 2). The phase of evaluation by farmers through on-farm testing of ICM components, was set up for mulch and fertilizing studies (Chapters 5 and 7, respectively), but was discontinued for external reasons. A Non Governmental Organisation (NGO), based in Jakarta and involved in agricultural projects in Indonesia, set up activities with hot pepper farmers. The ICM research results, obtained in Indonesia and reported in internal communications, were used. The author participated as a lecturer and resource person during a field school and in a workshop with some 20 vegetable farmers in March 1994. Farmers were challenged to reduce the use of pesticides, not only in hot pepper but also in other crops, to benefit ecological diversity and population build-up of natural enemies. As a result, 10 hot pepper farmers planned on-farm experiments with ICM components. An evaluation of on-farm trials was not yet available at the time of publication. With OFCOR as a research strategy, farmers should continuously be involved during follow-up research on ICM of hot pepper.

Appendix

Contingency tables used in correspondence analysis. For explanation of codes see Table 8.2.

Matrix I

	Vir1	Vir3	Vir3	Vir4	Σ
Cov1	15	31	16	19	81
Cov2	66	51	66	62	245
Cul1	42	52	58	4	156
Cul2	39	30	24	77	170
Per1	39	20	43	4	106
Per2	7	37	25	27	96
Per3	35	25	14	50	124
Mul1	17	40	48	61	166
Mul2	64	42	34	20	160
Nit1	17	10	30	15	72
Nit2	29	43	25	15	112
Nit3	25	20	13	24	82
Nit4	10	9	14	27	60
Σ	405	410	410	405	1630

Matrix II

	Yie1	Yie2	Yie3	Yie4	Yie5	Σ
Bed1	0	4	10	10	2	26
Bed2	41	41	35	28	25	170
Bed3	30	26	27	33	44	160
Cov1	13	22	19	27	18	99
Cov2	58	49	53	44	53	257
Cul1	43	51	51	46	31	222
Cul2	28	20	21	25	40	134
Mul1	68	55	39	30	16	208
Mul2	3	16	33	41	55	148
Nit1	21	17	13	15	2	68
Nit2	15	20	21	27	25	108
Nit3	14	11	5	14	38	82
Nit4	21	23	33	15	6	98
Per1	38	35	28	21	32	154
Per2	9	25	32	42	20	128
Per3	24	11	12	8	19	74
Σ	426	426	432	426	426	2136

Matrix III

	Yie1	Yie2	Yie3	Yie4	Yie5	Σ
Ant1	23	20	22	26	26	117
Ant2	16	25	25	21	23	110
Ant3	32	22	20	16	1	91
Cul1	43	51	51	46	31	222
Cul2	28	20	21	25	40	134
Fly1	32	23	23	27	39	144
Fly2	14	7	6	9	5	41
Fly3	7	15	18	21	4	65
Rai1	31	29	20	19	21	120
Rai2	17	22	32	36	45	152
Rai3	23	20	20	16	5	84
Thr1	12	9	12	14	4	51
Thr2	7	10	12	11	12	52
Thr3	13	6	3	5	24	51
Vir1	4	10	26	26	43	109
Vir2	10	22	21	31	18	102
Vir3	43	18	6	6	6	79
Σ	355	329	338	355	347	1724

Summary

Chapter 1

In Indonesia, hot pepper (*Capsicum* spp.) is the most important low elevation vegetable commodity in terms of production area and value. However, yield levels are low, due to poor crop health, low quality of seed material, and farmers' lack of production knowledge. In addition, farmers experience high production costs and fluctuating market prices. Integrated crop management (ICM) aims to overcome major problems with crop health by optimizing crop conditions. ICM appeared to be a suitable approach for vegetable production under tropical lowland conditions, as it was expected to lead to ecological, toxicological and socio-economic benefits.

Chapter 2

An exploratory field survey of farmers' practices in six major hot pepper production areas on Java, Indonesia, was conducted. In general, farmers produced their own hot pepper seed, with little selection for yield, quality and seed health, applied unbalanced fertilization with often high dosages of nitrogen, and used variable (low to extremely high) quantities of pesticides. Yields were low (1 to 3 t/ha), except in the production area of Brebes and Tegal (Central Java), where average yields were 12½ t/ha. To alleviate crop health problems, the following ICM components were selected: improved nursery practices, mulching and balanced fertilization.

Chapter 3

To observe crop health, pests and diseases were monitored in the field using incidence and/or severity observation keys. There were 11 major hot pepper pests and diseases. Vegetative stages of hot pepper were injured by cotton jassid, thrips, tropical armyworm and yellow tea mite. *Cercospora* leaf spot, viruses, bacterial wilt and southern blight were most harmful during and after fruit set. Anthracnose, cotton boll worm and oriental fruit fly were harmful during fruiting and harvesting stages. As phytophages occurred simultaneously, it was concluded that applied crop protection research had to concentrate on the crop and the complex of its harmful agents, rather than on a single pest or disease, in line with the ICM concept.

Chapter 4

As a potential contribution to ICM, various plant raising techniques were tested. The techniques studied included covering the nursery, raising transplants in pots and varying the duration of the nursery period. Screen-covered nurseries protected plants from aphids and aphid-transmitted viruses during the nursery phase, and, after transplanting, improved fruiting and crop production. Use of screen-covered nurseries should make application of pesticides during the plant raising phase superfluous. Potted transplants showed better crop establishment after transplanting than bare-root transplants and earlier harvesting. A nursery period of 1½ months appeared best for plant growth and earliness of harvesting. Raising plants in pots under a screen cover during 1½ months was proposed as an element of ICM. However, healthy and vigorous transplants yielded better only when other elements of ICM, such as mulching, were included during the field phase of the crop cultivation.

Chapters 5 and 6

Various types of mulch were investigated. Organic mulch was represented by rice straw, and inorganic mulches by white or silvery plastics. Rice straw mulch reduced soil temperature, induced faster plant growth, advanced mid-fruiting time, and caused higher potassium contents in leaves, but effects on crop production were not found. Rice straw mulch had variable effects on crop health. White and silvery plastic mulches increased soil temperature, induced faster plant growth and earlier fruiting, reduced phosphorus concentration in leaves and fruits, and increased nitrogen concentration in leaves and fruits. Plastic mulches reduced thrips severity and incidence, and delayed virus infection. The overall positive effect of plastic mulch on crop health contributed to improved crop production. Yield and mean fruit weight of healthy fruits were increased and harvesting time was advanced. The combination of improved crop performance, health and production with increase of fertilizer efficiency, control of evaporation, leaching and soil erosion by the plastic mulches fitted the concept of ICM. To minimize the negative side-effect of plastic waste on the environment, further improvement of the mulch technology is required. Preliminary on-farm field experiences and a tentative cost-benefit analysis were in favour of the application of plastic mulch in hot pepper under tropical lowland conditions.

Chapter 7

Effects of nitrogen application rates were studied in growth chamber and field trials. In pot experiments in the growth chamber, effects of nitrogen application rates on severity of *Cercospora* leaf spot were studied. Fertilizing with nitrogen improved plant growth, but did not influence fruiting time. Increasing nitrogen application rates aggravated anthracnose fruit rot in one field trial and *Cercospora* leaf spot in growth chamber trials. Negative correlations were found between nitrogen levels in leaves, and blossom mould and thrips incidence. Fertilization with a moderate nitrogen application rate of 150 kg/ha gave the highest yields in most field trials. Mean fruit weight and harvesting time were not affected by nitrogen dosages. With increasing nitrogen dosages, higher nitrogen levels in leaves and fruits were found. Moderate amounts of nitrogen, balanced with appropriate rates of phosphorus and potassium, were recommended as a fertilizer component of ICM.

Chapter 8

In order to evaluate 16 ICM field trials, with various experimental designs and conducted in different production situations, results were analyzed using the descriptive statistical method of correspondence analysis. Cultural practices, such as nursery practices, mulching, nitrogen fertilizing and type of cultivar were combined with virus infection and with healthy yield. Variables of crop health were also combined with healthy yield. Low values for virus infection were closely associated with plastic mulching, and high virus with high nitrogen application. Increase of nitrogen was associated with increase of yield until moderate applications of nitrogen. Low yield was associated with no plastic mulching. Yield was strongly associated with virus infection. Cultural practices benefitted crop production through, among others, improvement of crop health. Type of cultivar or location did not influence effects on yield by nursery period, type of seed bed, mulching or nitrogen fertilizing.

Samenvatting

Hoofdstuk 1

Hete peper (*Capsicum* spp.) is het belangrijkste groentegewas, qua produktie-areaal en economische waarde in de laaglanden van Indonesië. De opbrengsten zijn echter laag als gevolg van problemen met de gezondheidstoestand van het gewas, slechte kwaliteit van het zaad en het gebrek aan kennis van teeltwijze bij de boeren. Bovendien zijn produktiekosten hoog en fluctueren de marktprijzen sterk. Geïntegreerde teeltwijze (GT) heeft als doel de gezondheidstoestand van het gewas te verbeteren door het optimaliseren van de teeltomstandigheden. GT lijkt een passende benadering voor de groenteteelt in tropisch laagland, omdat het waarschijnlijk ecologische, toxicologische en sociaal-economische voordelen oplevert.

Hoofdstuk 2

In de zes belangrijkste teeltgebieden op Java in Indonesië werden enquêtes gehouden. Over het algemeen vermeerderden boeren zelf zaad, maar selecteerden weinig op opbrengst, kwaliteit en gezondheid. De bemesting was niet gebalanceerd, met vaak hoge stikstofgiften, en het pesticiden gebruik was variabel (laag tot extreem hoog). De opbrengsten waren laag (1 tot 3 t/ha), behalve in het teeltgebied in Brebes en Tegal (Midden Java), waar de gemiddelde opbrengst 12½ t/ha bedroeg. Om de gezondheidstoestand van het gewas te verbeteren werden de volgende componenten van GT geselecteerd: verbeterde opkweekmethodes, toepassing van mulch en gebalanceerde bemesting.

Hoofdstuk 3

De gezondheid van het gewas werd geobserveerd met behulp van waarnemings-schalen voor het voorkomen en/of de hevigheid van ziekten en plagen. Er waren 11 belangrijke ziekten en plagen van hete peper, waarvan jassiden, trips, de eiernest-rups en de gele bladmijt schadelijk waren tijdens de vegetatieve fase. *Cercospora* bladvlekkenziekte, virussen, bacterieverwelkingsziekte en sclerotiumziekte waren vooral schadelijk tijdens en na de vruchtzettingsfase. Antraknose vruchtrot, maiskolfrups en fruitvlieg waren schadelijk tijdens vruchtzettings- en oogstfasen. Omdat diverse fytofagen tegelijkertijd voorkwamen, werd geconcludeerd dat toegepast onderzoek aan gewasbescherming zich zou moeten concentreren op het gewas en het complex van schadelijke organismen, in plaats van op een enkele ziekte of plaag.

Hoofdstuk 4

Als mogelijke bijdrage aan GT werden verschillende methoden van plantenopkweek getest. De bestudeerde technieken bestonden uit het afschermen van het kweekbed, het opkweken in potjes en het variëren van de opkweekperiode. Tijdens de opkweekfase werden plantjes tegen luizen en tegen door luis overgedragen virussen beschermd door de kweekbedden af te dekken met luisdicht gaas. Deze maatregel vervroegde de vruchtzetting en verbeterde de produktie in het veld. Gebruik van gaas over kweekbedden maakte chemische bestrijding tijdens de opkweekfase overbodig. In potjes opgekweekt plantmateriaal sloeg beter aan na overplanten in het veld en produceerde eerder dan niet opgepotte zaailingen. De optimale opkweekperiode voor plantegroei en vroegheid van oogst in het veld was 1½ maand. Het opkweken van plantjes in potten onder gaas gedurende 1½ maand werd aanbevolen als een onderdeel van GT. Gezonde en groeikrachtige plantjes produceerden echter alleen beter wanneer tevens andere elementen van GT, zoals het gebruik van mulch, tijdens de veldfase van de teelt werden toegepast.

Hoofdstukken 5 en 6

Diverse soorten mulch werden getest. Als organische mulch werd rijststro gebruikt en als anorganische mulch witte en zilverachtige plastic folies. Rijststro mulch verlaagde de bodemtemperatuur, induceerde snellere plantegroei, vervroegde de vruchtzetting en veroorzaakte hogere kaliumgehaltes in het blad. Effecten op de opbrengst werden echter niet gevonden. Rijststro mulch had wisselende effecten op de gezondheidstoestand van het gewas. Plastic mulch verhoogde de bodemtemperatuur, induceerde snellere plantegroei en vroegere vruchtzetting, verlaagde de fosfor- en verhoogde de stikstofconcentraties in bladeren en vruchten. Plastic mulch verlaagde het voorkomen en de hevigheid van trips en vertraagde virus-infectie. Het positieve effect van plastic mulch op de gezondheid van het gewas droeg bij aan een hogere opbrengst. De totale opbrengst en het gemiddelde vruchtgewicht van gezonde vruchten werden verhoogd en de oogstperiode werd vervroegd. Op grond van de gunstige effecten werd geconcludeerd dat mulchen met wit of zilverachtig plastic als maatregel past binnen GT. Een verdere verbetering van de mulch-technologie is nodig om het negatieve aspect van plastic op het milieu te minimaliseren. Voorlopige ervaringen in praktijkpercelen en een eenvoudige kosten/baten analyse ondersteunden de aanbeveling om plastic mulch toe te passen bij hete-peperteelt in het tropisch laagland.

Hoofdstuk 7

Effecten van stikstofgiften op de groei en ontwikkeling, de gezondheid en de opbrengst van het gewas werden bestudeerd in veldexperimenten en in proeven in klimaatcellen. Bemesting met stikstof verbeterde de plantegroei, maar beïnvloedde het tijdstip van de vruchtzetting niet. Het verhogen van stikstofgiften verergerde antraknose vruchtrot in een veldproef en *Cercospora* bladvlekkenziekte in klimaatcelproeven. Negatieve correlaties werden gevonden tussen stikstofniveaus in de bladeren en het voorkomen van *Choanephora* schimmelziekte en trips. Bemesting met een matige stikstofgift van 150 kg/ha gaf de hoogste opbrengsten in de meeste veldproeven. Het gemiddelde vruchtgewicht en het tijdstip van de oogstperiode werden niet beïnvloed door de hoogte van de stikstofgift. Verhoging van de stikstofgift resulteerde in hogere stikstofgehaltes in zowel bladeren als vruchten. Matige hoeveelheden stikstof, gecombineerd met evenredige fosfor- en kaliumgiften, werden aanbevolen als een bemesting-strategie binnen GT.

Hoofdstuk 8

Voor een samenvattende analyse van 16 verschillende GT veldproeven, uitgevoerd onder variabele produktie-omstandigheden, werd gebruik gemaakt van een beschrijvende statistische methode: de correspondentie-analyse. Cultuurmaatregelen, zoals opkweekmethode, mulchen, stikstofbemesting en rassenkeuze werden gecombineerd met virus infectie en met opbrengst. Variabelen van de gezondheidstoestand van het gewas werden gecombineerd met opbrengst. Lage waarden voor virusinfectie waren nauw geassocieerd met mulchen met plastic en hoge virusinfectie met hoge stikstofgiften.

Verhoging van de stikstofgift, tot matige hoeveelheden, ging gepaard met verhoging van opbrengst. Lage opbrengst was geassocieerd met afwezigheid van plastic mulch. De opbrengst was nauw geassocieerd met virusinfectie. Cultuurmaatregelen bevorderden de produktie onder andere door verbetering van de gezondheidstoestand van het gewas. De effecten van opkweekperiode, type zaaibed, mulchen of stikstofbemesting op de opbrengst werden niet beïnvloed door type ras of locatie.

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Acknowledgements

This book is the result of several years' research work, but could not have been prepared without the cooperation and support of many colleagues, students and friends.

I would like to especially mention Prof.Dr. J.C. Zadoks for being my principal supervisor. His guidance, his keen interest in the research subject and his contribution of new ideas inspired me time after time. I am grateful to my advisor Ir. H.D. Frinking, for his support, wherever I stayed, and the scientific discussions.

The research was mainly executed at the Lembang Horticultural Research Institute (LEHRI) in Indonesia, at the Wageningen Agricultural University (WAU) in the Netherlands and at the Malaysian Agricultural Research and Development Institute (MARDI) in Malaysia. I very much appreciate the cooperation of LEHRI, WAU and MARDI staff. My Dutch colleagues of the Agricultural Technical Assistance (ATA-395) project at LEHRI are gratefully acknowledged.

I mention my Indonesian counterparts and co-authors of publications included in this book: Dr. A.S. Duriat, Ir. N. Nurtika, Ir. N. Sumarni, Ir. R. Sutarya, and Ir. T.S. Uhan with appreciation for their valuable contributions. I gratefully acknowledge Dr. G.A.M. van Marrewijk, Dr. G.J.H. Grubben and Dr. G.J.M. Vos for critically reading the manuscripts.

I thank the WAU MSc-students Edwin van der Vossen, Geert Koning, Fons Blijlevens, Sandra Bot, and Trinette van Selling, for taking part in the ICM research.

Special thanks are also conveyed to all colleagues who supported me at the following institutions/organisations: in Indonesia Agency for Agricultural Research and Development (AARD) Jakarta, Centro Internacional de la Papa (CIP) Lembang, Dinas Pertanian (DP) Java, East West Seed Purwakarta, Pesticide Action Network (PAN) Jakarta, Plant Resources of Southeast Asia (PROSEA) Bogor, and World Education (WE) Jakarta; in Malaysia Commonwealth Agricultural Bureau International (CABI) Kuala Lumpur, Malaysian Plant Protection Society (MAPPS) Serdang, Nestlé Petaling Jaya; in Taiwan Asian Vegetable Research and Development Centre (AVRDC) Tainan; in France Organisation de Recherches Scientifiques et Techniques d'Outre-Mer (ORSTOM) Montpellier; in the Netherlands AKZO Arnhem, Centrum voor Planten Reproductie Onderzoek (CPRO-DLO) Wageningen, Instituut voor Planteziektenkundig Onderzoek (IPO-DLO) Wageningen, Landbouw Economisch Instituut (LEI-DLO) Den Haag, Mitol Amsterdam, Proefstation Akkerbouw en Groenten in de Volle grond (PAGV) Lelystad, Planteziektenkundige Dienst (PD-DLO) Wageningen, Proefstation Tuinbouw Onder Glas (PTOG) Naaldwijk, and Universiteit van Amsterdam (UVA) Amsterdam.

Furthermore, I am thankful to C. Lilies S. for the translation of this book into Indonesian, and to Dr. E. van de Fliert for the editing and assistance to realize the Indonesian version of this book.

The Dutch Ministry of Foreign Affairs (DGIS), the Foundation "Johanna Westerdijkfonds" and the Foundation Landbouw Export Bureau 1916/1918 are acknowledged for financial support.

Tenslotte wil ik alle vrienden en familie, met name mijn vader, Trudy en Albert, hartelijk bedanken voor hun belangstelling en steun tijdens de afgelopen jaren.

Curriculum vitae

Johanna Gertruda Maria (Janny) Vos werd geboren op 9 oktober 1962 in Zuidelijke IJsselmeerpolders, Flevoland. In 1981 behaalde zij het VWO-diploma aan het Lambert Franckens College te Elburg, Gelderland. Van september 1981 tot januari 1988 volgde zij de studie Plantenveredeling aan de Landbouwuniversiteit Wageningen (LUW). De doctoraalstudie bestond uit de afstudeervakken Plantenveredeling, Fytopathologie, Erfelijkheidsleer en Informatica. Haar stage van een half jaar bracht zij door aan het Centro Internacional de la Papa in Perú. In maart 1988 werd zij aangesteld door het Directoraat Generaal Internationale Samenwerking (DGIS) ten behoeve van het project 'Strengthening research and development of lowland vegetables in Indonesia'. Zij werd uitgezonden naar het Lembang Horticultural Research Institute in West Java, en werkte aan de geïntegreerde teeltwijze van hete peper (*Capsicum* spp.). Een deel van de uitgevoerde activiteiten is beschreven in dit proefschrift. Na de voortijdige beëindiging van het project in april 1992, werkte zij in Nederland op vrijwillige basis, als gastmedewerker bij de vakgroep Fytopathologie van de LUW, aan een aantal proeven in klimaatcel en kas. Van februari 1993 tot april 1994 deed zij veldonderzoek, met financiële ondersteuning van DGIS, bij het Malaysian Agricultural Research and Development Institute te Klang, Selangor Darul Ehsan, Maleisië. De resultaten van de proeven in Nederland en Maleisië zijn in dit proefschrift verwerkt. Tijdens korte bezoeken aan Indonesië in januari en maart 1994 werkte zij samen met World Education Jakarta aan de opzet van kleinschalig projecten met hete peper telers in Yogyakarta en Noord Sumatra. Van februari tot augustus 1994 was zij tijdelijk aangesteld als wetenschappelijk medewerker bij de vakgroep Fytopathologie van de LUW voor de afronding van het onderzoek aan hete peper.

Johanna Gertruda Maria (Janny) Vos was born on October 9th, 1962, in Zuidelijke IJsselmeerpolders, Flevoland, the Netherlands. In 1981 she finished High School and began to study Plant Breeding at the Wageningen Agricultural University (WAU). Major subjects were Plant Breeding, Phytopathology, Genetics and Computer Science. A practical period of half a year was spent at the Centro Internacional de la Papa in Peru. She passed her MSc examination in January 1988. In March 1988 she became associate expert in a development project 'Strengthening research and development of lowland vegetables in Indonesia' of the Dutch Ministry of Foreign Affairs (DGIS). She worked at the Lembang Horticultural Research Institute in West Java on integrated crop management of hot pepper (*Capsicum* spp.) in tropical lowlands. Part of the research activities is reported in this book. After the untimely termination of the project in April, 1992, she continued the research in growth chamber and greenhouse at the Department of Phytopathology (WAU) as a voluntary associated researcher. From February, 1993, until April, 1994, she conducted field research with financial support from DGIS at the Malaysian Agricultural Research and Development Institute at Klang, Selangor Darul Ehsan, Malaysia. Results of experiments in the Netherlands and Malaysia are reported in this book. During short visits to Indonesia in January and March, 1994, she was a resource person on behalf of World Education Jakarta for the initiation of small-scale projects with hot pepper farmers in Yogyakarta and North Sumatra. From February until August 1994, she was employed by the Department of Phytopathology (WAU) as an associate scientist to finalize the hot pepper research.

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List of publications

Publications included in this thesis

Vos, J.G.M. and Duriat, A.S., 1994.
Hot pepper (*Capsicum* spp.) production on Java, Indonesia: toward integrated crop management. Crop Protection. In press.

Vos, J.G.M. and Frinking, H.D., 1994.
Nitrogen fertilizing as a component of integrated crop management of hot pepper (*Capsicum* spp.) under tropical lowland conditions. Submitted.

Vos, J.G.M. and Frinking, H.D., 1994.
Pests and diseases of hot pepper (*Capsicum* spp.) in tropical lowlands of Java, Indonesia. Submitted.

Vos, J.G.M. and Nurtika, N., 1994.
Plant raising techniques as components of integrated crop management of hot pepper (*Capsicum* spp.) under tropical lowland conditions. Submitted.

Vos, J.G.M and Sumarni, N., 1994.
Integrated crop management of hot pepper (*Capsicum* spp.) under tropical lowland conditions: effects of mulches on crop performance and production. Submitted.

Vos, J.G.M. and Zadoks, J.C., 1994.
Evaluation of components of integrated crop management of hot pepper (*Capsicum* spp.) in various production situations. In preparation.

Vos, J.G.M., Nurtika, N. and Sumarni, N., 1994.
An exploratory survey on farmers' practices and management of hot pepper (*Capsicum* spp.) on Java, Indonesia. Journal of Plant Protection in the Tropics. In press.

Vos, J.G.M., Uhan, T.S. and Sutarya, R., 1994.
Integrated crop management of hot pepper (*Capsicum* spp.) under tropical lowland conditions: effects of mulches on crop health. Crop Protection. Accepted.

Other publications

Grubben, G.J.H., Suwandi, de Jager, A. and Vos, J.G.M., 1994.
Integrated crop management (ICM) using a farmer-oriented approach in a lowland vegetable production area in Indonesia. Paper presented at the XXIVth International Horticultural Congress, ISHS, August 21-27, Kyoto, Japan.

Vos, J.G.M., Sastrosiswojo, S., Uhan, T.S. and Setiawati, W., 1991.
Thrips on hot peppers in Java, Indonesia. In Thrips in Southeast Asia: proceedings of a regional consultation workshop (ed. by N.S. Talekar), Bangkok, Thailand, 13 March 1991. Asian Vegetable Research and Development Center, AVRDC Publication 91-342: 18-28.

Wijbrandi, J., Vos, J.G.M. and Koornneef, M., 1988.
Transfer of regeneration capacity from *Lycopersicon peruvianum* to *L. esculentum* by protoplast fusion. Plant Cell, Tissue and Organ Culture 12: 193-196.

Wijbrandi, J., Posthuma, A., Kok, J.M., Rijken, R., Vos, J.G.M. and Koornneef, M., 1990.
Asymmetric somatic hybrids between *Lycopersicon esculentum* and irradiated *L. peruvianum*. I. Cytogenetics and morphology. Theoretical and Applied Genetics 80: 305-312.