Appendix 1

Case study USA

Subsistence & exploitation

During the 1940s, the USA government policies incentivized the uptake of high yielding crop varieties to enhance agricultural productivity. Cotton growers in southern Texas readily switched to these high yielding cotton varieties that were susceptible to insect attack (e.g. boll weevil, *A. grandis*), which made growers extremely reliant on the use of pesticides (Fig. A1.1). Growers lowered their pest damage thresholds in cotton, reinforcing the adoption of chemical pesticides (Cowan and Gunby 1996). By the mid-1950s key pests of cotton (*A. grandis*, cotton fleahopper (*Pseudatomoscelis seriatus*) and pink bollworm (*Pectinophora gossypiella*)) had developed resistance to frequently applied insecticides (e.g. DDT, dieldrin). As a response, new mixtures of insecticides were introduced, and dosages and application frequencies increased.

Crisis & disaster

The response to pest outbreaks resulted in initial effective control of key pests, but stimulated a resurgence of secondary pests, which became key pests. By 1968 almost 200,000 ha of cotton was grown in Texas (Adkisson et al. 1982). Secondary pests developed resistance against all insecticides used and inflicted severe damage to cotton, causing complete crop failure, and resulting in a shrinking of the cotton production area in Texas to 64,000 ha in 1975 (Adkisson et al. 1982, Cowan and Gunby 1996).

In the 'rest of Texas' (Fig. A1.1B) and the area of Trans-Pecos (Fig. A1.1C) new insecticides (organophosphates) were introduced as a response to resistance development to organochlorines, and dosages and application frequencies increased. This response resulted in effective suppression of key pests, but stimulated a resurgence of secondary pests (*H. zea*, tobacco budworm (*Heliothis virescens*) and cabbage looper (*Trichoplusia ni*)), which in turn became key pests (Adkisson et al. 1982, Cowan and Gunby 1996). In the 'rest of Texas' (Fig. A1.1B), at the end of the 1960s, cotton pests, such as *A. grandis*, *P. seriatus* and *P. gossypiella,* were not controlled by organophosphates due to resistance. In the Trans-Pecos area (Fig. A1.1C) cotton growers continued using pesticides, because they thought the alternative was too complex and pesticides were simple to use based on calendar applications or signs of crop damage. Uncertainty about the efficacy of IPM contained growers locked-in in a pesticide dependent state (Cowan and Gunby 1996).

Escape & reorganization

In response to insecticide resistance alternative paths were explored by cotton growers in Texas. Cotton growers on the High Plains of Texas (Fig. A1.1A) were quickly returning to IPM practices. In a coordinated effort to control pests, cotton growers in this area applied uniform delayed planting of cotton, limiting the need to use insecticides. Cotton growers in 'the rest of Texas' (Fig. A1.1B) also switched back to IPM as a pest management method, but switching costs were alleviated by government extension programs and state legislation was implemented to coordinate the adherence of farmers to a short growing season (Cowan and Gunby 1996). This addresses the importance of coordination efforts to overcome 'excess inertia' – the willingness to adopt a new technology knowing other will adopt the technology as well. Despite these efforts only a small group of farmers in Trans-Pecos switched to IPM

(Fig. A1.1C), which was attributed to a lack of coordination mechanisms in overcoming the lock-in (Adkisson et al. 1982, Cowan and Gunby 1996).

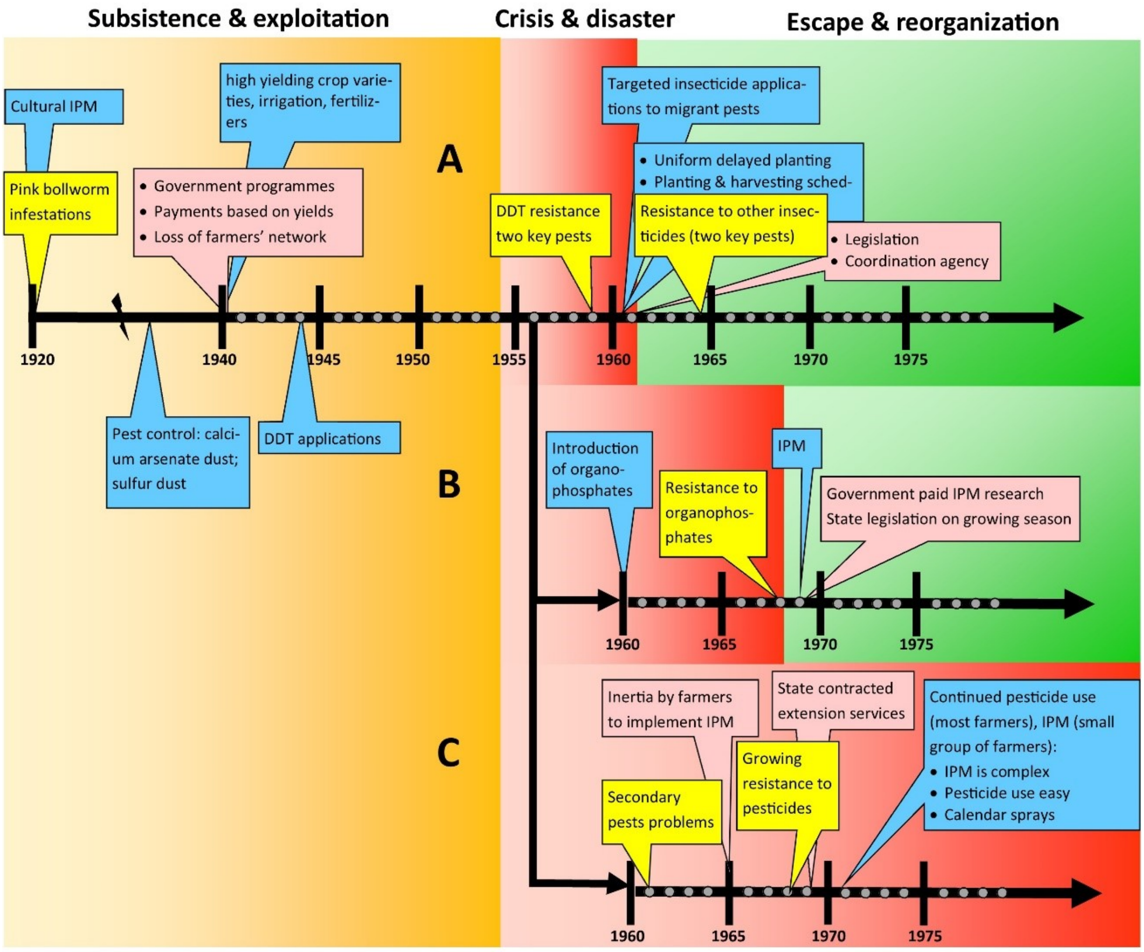

Figure A1.1: *Timeline representing enabling and disabling drivers (text balloons) of pesticide use in cotton production in Texas, USA from 1920-1980. Colours referring to domains in the framework: farming (yellow), agro-landscapes* **(***green), science & technology (blue), and society (pink). The colours in the background (orange-red-green) indicate the transition to a new phase of the treadmill.*

Case study Costa Rica

Subsistence & exploitation

The pest management dynamics in banana production in the Golfito zone in Costa Rica (Fig. A1.2) provides another case study of interactions within the framework driving the pesticide treadmill. Thrupp (1990) portrays how a combination of ecological and socio-political drivers resulted in overuse of broad-spectrum pesticides, leading to insecticide resistance and secondary pests. A pesticide treadmill was initiated with calendar-scheduled applications of dieldrin against red rust thrips (*Chaetanophothrips orchidii*) and the banana corn weevil (*Cosmopolites sordidus*), which caused a resurgence of a secondary pest banana stalk borer (*Castniomera humbolti*) and the platynota moth (*Platynota rostrana*) (Stephens 1984, Thrupp 1990).

Crisis & disaster

Despite heavy spraying with organochlorine insecticides (dieldrin, DDT, endrin and heptachlor) and malathion and diazinon, these pests were not controlled, and by the late 1960s high economic losses undermined profits (Thrupp 1990). The pressure to fulfil production goals, maximizing yields and comply with aesthetic quality standards led to high risk attitude among managers of banana plantations and resulted in a high-input response to control pests (Thrupp 1990). To control resistant insects by 1960, dieldrin was replaced by carbaryl to control insect defoliators and the banana moth (*Antichloris viridis*), and toxaphene was used for control of West Indian Bagworm (*Oiketicus kirbyi*). By 1962 banana moths and corn weevils had developed resistance against dieldrin, but heavy spraying continued. There was an information gap regarding pesticide resistance, resurgence and secondary outbreaks, and the agrochemical industry was the most dominant source of information and publicity on pest control from 1950-1980. When resistance problems arose, industry advised banana plantation managers to switch to new insecticides. Although additional sources of information (e.g. government agencies or scientific journals) were consulted, they were given little attention. Risk perception of the managers was mainly shaped by production goals, information from the agrochemical industry and their fear of pests, which refrained managers from adopting alternative methods or approaches (Thrupp 1990). For example, even though it was already demonstrated in 1965 that banana plants could tolerate some defoliation, it took another thirteen years before a damage threshold level was adopted that took this into account (Stephens 1984). While field staff was well positioned to make informed location-specific decisions on pest management, the top-down centralized decision making on pest management did not allow this (Thrupp 1990).

Escape & reorganization

The overuse of insecticides in banana production in Costa Rica (Fig. A1.2) began to undermine profits in the early 1970s. Combined with an increased awareness of the pest problem this led to an increase in economic damage threshold levels. After raising this threshold, insecticide use began to decrease gradually. However, a successful change in insect control was initiated in 1973 with a total ban on all insecticides. This allowed for the re-establishment of natural enemies and within two years insect pests nearly disappeared (Stephens 1984, Thrupp 1990).

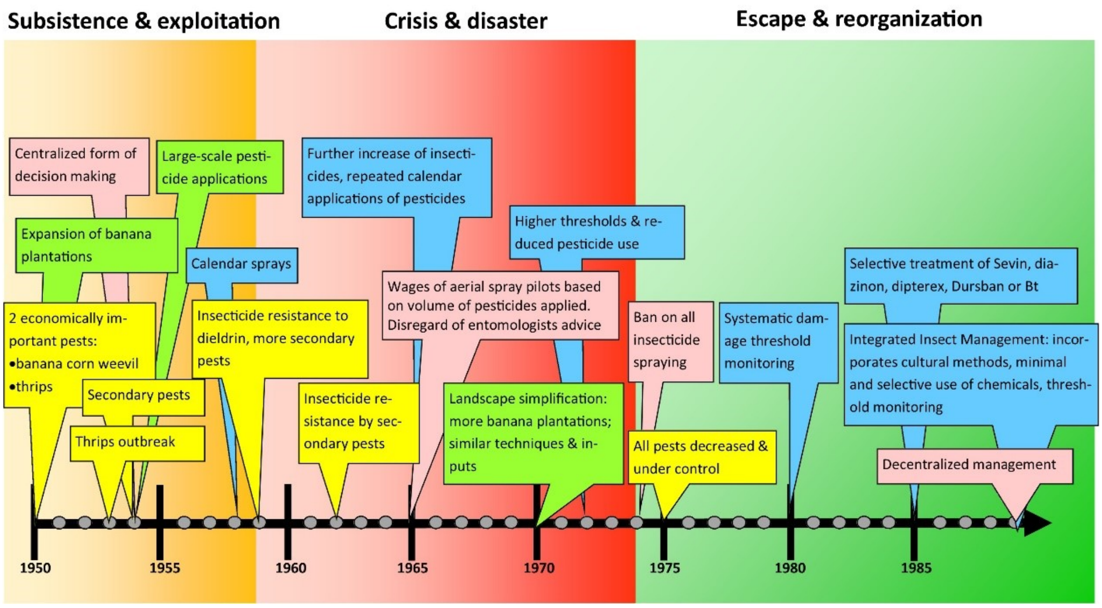

Figure A1.2: *Timeline representing enabling and disabling drivers (text balloons) of pesticide use in banana production in the Golfito zone, Costa Rica from 1950-1990. Colours referring to domains in the framework: farming (yellow), agro-landscapes* **(***green), science & technology (blue), and society (pink). The colours in the background (orange-red-green) indicate the transition to a new phase of the treadmill.*

Case study Indonesia

Subsistence & exploitation

A fifth case is on rice production in Indonesia (Fig. A1.3). Rice production in Indonesia intensified in the 1960s as a result of rice intensification programs. Farmers were provided with a technology package consisting of short-duration, high-yielding rice varieties, nitrogen and phosphate fertilizers, insecticides and fungicides by the government. Farmers were obliged to use the whole package and applied pesticides on calendar-based regime, while problems due to yellow stem borers (*Scirpophaga incertulas*) maintained (Oka 1991, Settle et al. 1996, Thorburn 2015).

Crisis & disaster

Government undertook contracts with insecticide firms for pest management activities, which included aerial applications of phosphamidon and diazinon to control stemborers. When a secondary pest, the brown planthopper (*Nilaparvata lugens*), emerged, the government provided loans and subsidies for agrochemicals to farmers. Another method to manage the brown planthopper was the development of resistant rice varieties (IR36) in the early 1980s, and the brown planthopper stopped being a problem until 1986. In 1984 Indonesia became self-sufficient in rice production. However, rice farmers were still dependent on chemical-based pest management to control pest outbreaks from green leaf hoppers (*Nephotettix malayanus* and *Nephotettix virescens*) and white stemborer (*Scirpophaga innotata*) (Oka 1991, Settle et al. 1996, Thorburn 2015).

Escape & reorganization

A large outbreak of the brown plant hopper in 1986 urged the president to ban 57 pesticides, along with the elimination of subsidies for insecticides. At the same time, IPM was introduced as the official state-endorsed approach to pest management and a large-scale program for farmer training in IPM was initiated. The program emphasized on-farm training that increased farmers' independence to implement IPM with as little external assistance as needed. Specific training was on pest surveillance, host-plant resistance, natural enemies of pests, judicious use of pesticides and field demonstrations that gave farmers first-hand experience with IPM practices and ecological concepts (Oka 2003, Bottrell and Schoenly 2012). Around 1.5 million farmers in Indonesia received training, and together with national IPM policies, insecticide use was reduced by as much as 75% (Oka 1991, 2003, Settle et al. 1996, Bottrell and Schoenly 2012).

Crisis & disaster
The Asian Financial crisis in 1997-1998 hit Indonesia hard, and in combination with the political and economic turmoil in Indonesia during that period, many political and institutional changes have caused the National IPM Program to be degraded. In 2009, new outbreaks of the brown planthopper were reported with significant crop losses (Bottrell and Schoenly 2012). Concurrently, farmers started spraying again. This relapse to pesticide use is, amongst others, caused by insecticide resistance, deregulation and liberalization of trade and investment, decentralization of decision-making, and loss of communication pathways between agricultural research and extension services (Thorburn 2015).

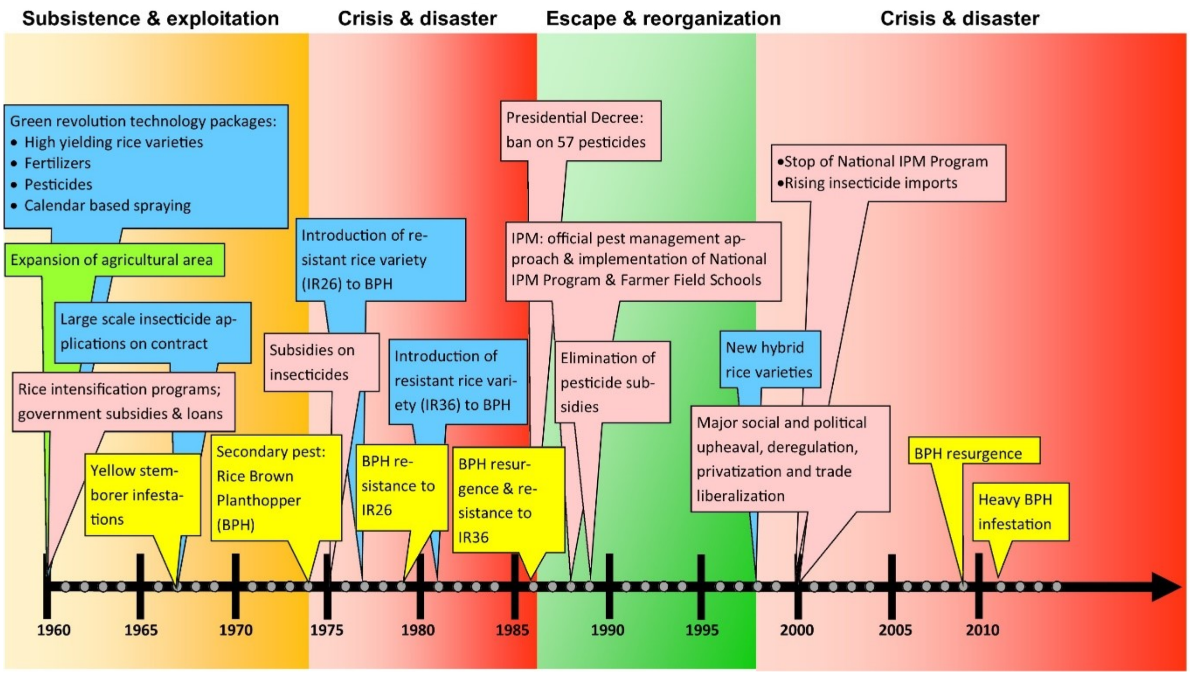

Figure A1.3: *Timeline representing enabling and disabling drivers (text balloons) of pesticide use in rice production in Indonesia from 1960-2015. Colours referring to domains in the framework: farming (yellow), agro-landscapes (green), science & technology (blue), and society (pink). The colours in the background (orange-red-green) indicate the transition to a new phase of the treadmill.*

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