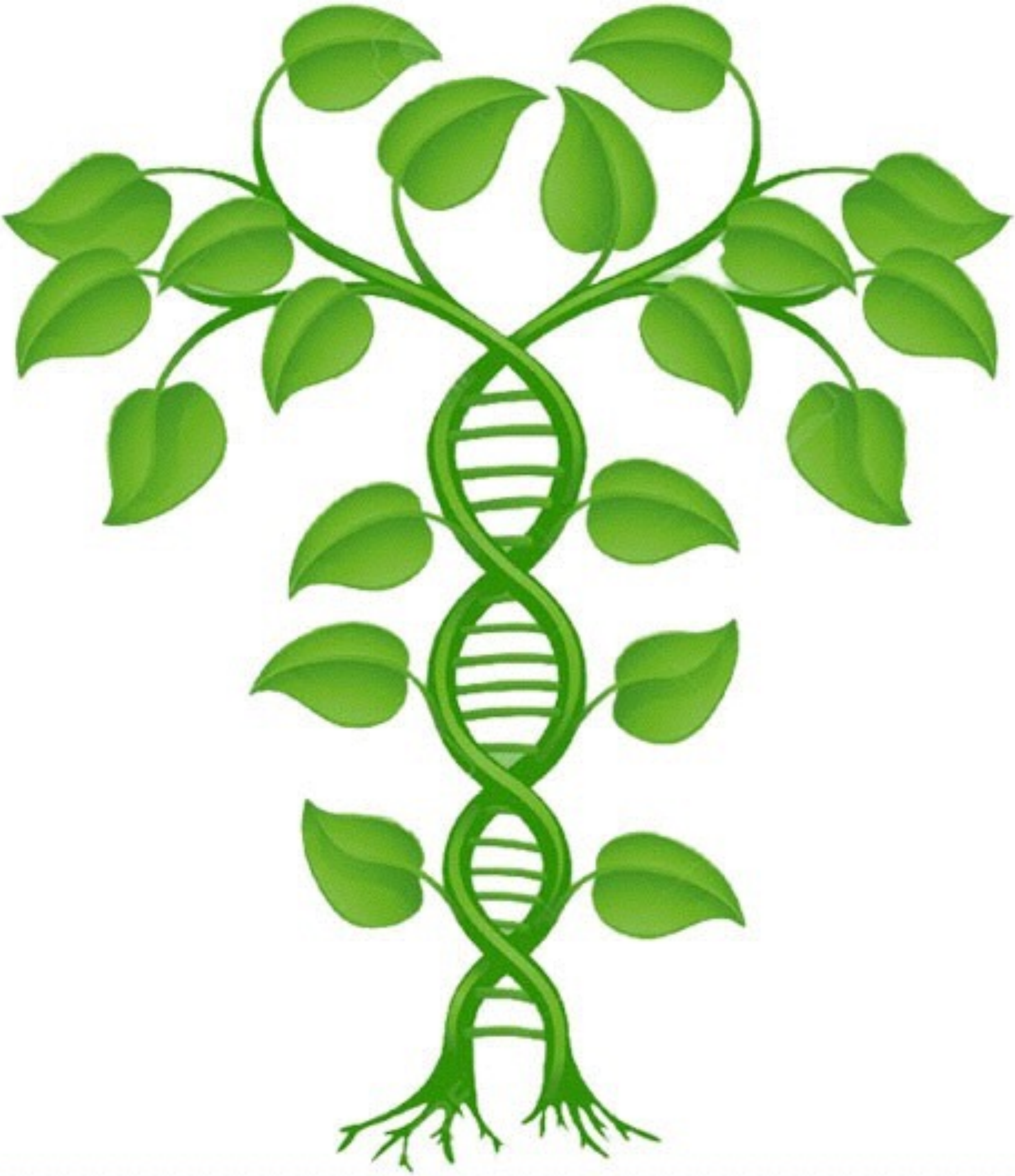
Genetic Engineering and the Existence of Monocultures

A case study of Panama disease



Thesis MMW / 19-06-2015

Abstract

The threat to food security caused by the existence of monocultures is serious. Monocultures of genetically engineered crops are spreading. In this paper an exploration will be made of most important literature on the link between genetic engineering and monoculture existence. The analysis of the case study of Panama disease will be made following four steps. This will result in the presentation of two causal models of the monocultures of banana types 'Gros Michel' and 'Cavendish'. From the causal models will be derived what the main causes are for monoculture existence and what the role of genetic modification is in context of the case. From these results will be concluded to what extent genetic engineering influences the existence of monocultures.

Structure of the paper

The first chapter consists of an introduction to the subject and presentation of the research question. In chapter two I have presented the theoretical framework, in which the dependent and independent variables are contextualized. In chapter three the method is described, which I used to analyze a case study. The analysis of the case study is presented in chapter four. The results of this analysis are presented in two causal models regarding two monocultures in chapter five. Chapter six provides a discussion of the choices that were made in the paper. Chapter seven concludes the paper, answering the research question and making recommendations for future research.

Table of contents

1. Introduction pp. 3-4

2. Theoretical framework pp. 5-7

3. Method of approach pp. 8-9

4. Case study: Panama disease

   4.1. Short introduction to the case p. 10

   4.2. Causes for the existence of the 'Gros Michel' monoculture pp. 10-11

   4.3. Abandonment of 'Gros Michel' and genetic engineering p. 12

   4.4. Genetic engineering and the 'Cavendish' monoculture p. 13

5. Results pp. 14-16

6. Discussion p. 17

7. Conclusion p. 18

Bibliography pp. 19-20

1. Introduction

> "The president of Nabisco once defined the goal of economic globalization as 'a world of homogenous consumption,' in which people everywhere eat the same food, wear the same clothing, and live in houses built from the same materials. It is a world in which every society employs the same technologies, depends on the same centrally managed economy, offers the same education for its children, speaks the same language, consumes the same media images, holds the same values, and even thinks the same thoughts – monoculture." (Kimbrell, 2002)

The goal Nabisco's president described has, regarding agriculture, been reached. Monocultures have increased dramatically worldwide and ninety-one percent of the 1.5 billion hectares of cropland is planted in monocultures to single crops such as wheat, rice, maize, cotton, and soybean. (Altieri, 2004)The amount of these crops that are genetically engineered is increasing as well. The global arable land area devoted to transgenic crops increased 4.5-fold from 2.8 million hectares in 1996 to 12.8 million hectares in 1997, and no less than 30 million hectares in 1998. The United States accounted for 64 percent of the global acreage, followed by China and Argentina. (Altieri, 2000) Genetic engineering technology holds exceptional promise for improving agricultural production and keeping it environmentally sound. (Paoletti & Pimentel, 1996) Potential benefits include higher productivity of crops and livestock, increased pest control and reduced pesticide use, reduced fertilizer use and improved conservation of soil and water resources. (Paoletti & Pimentel, 1996) For example, theoretically, pests could be managed more easily within genetically engineered crops. (Garcia & Altieri, 2005) There are no studies, however, that support long-term effects. The longest experiment with genetically engineered crops only lasted three years. (Garcia & Altieri, 2005)

Biotechnology has to be studied more intensively as it promotes single-crop solutions, causing monocultures to exist. (Altieri, 2004) Monocultures are a problem because they lack diversity, which makes them more susceptible to disease, as was shown in a study of Zhu, et al. (2000) The crop in that case had 89 percent greater yield and disease was 94 percent less severe when grown in mixtures compared to growth in monoculture. (Zhu, et al., 2000)The susceptibility to plant disease could be a real problem regarding food security. The definition of food security is: '…when all people, at all times, have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life.' (Pinstrup-Andersen, 2009) The decrease in crop diversity and possible disappearance of species could lead to a decline in food availability, threatening food security. (Pinstrup-Andersen, 2009) It is therefore important to study the causes of the existence of monocultures. The link between monocultures and genetic engineering can be derived from literature but it is not clear yet how big the influence of genetic engineering is.

The goal of this paper is to map the different causes for monoculture existence and discuss the amount of influence of genetic engineering has. I will first present existing literature on the subject, discussing the context in which genetic engineering and monocultures interact. This will result in the presentation of a conceptual model. Next, I will explain the steps I used for further analysis of a case study of Panama disease. From this, the causes for monoculture existence can be derived and the influence of genetic engineering can be discussed. Analysis of the case study will result in the presentation of two causal models and an answer to the research question: 'To what extent does genetic engineering influence the existence of monocultures?'

2. Theoretical framework

The influence of genetic engineering in literature is often described as positive. Biotechnology companies often claim that genetically engineered organisms are essential scientific breakthroughs needed to feed the world and reduce poverty in developing countries. 'The view rests on two critical assumptions: 1. hunger is due to a gap between food production and human population density or growth rate and 2. genetic engineering is the best or only way to increase agricultural production to meet future food needs.' (Altieri, 2004) These assumptions however are invalid, because there is no relationship between the prevalence of hunger in a given country and its population, as there is more food per habitant being produced in the world than ever before. (Altieri & Rosset, 1999) Moreover, most innovations in industrial agriculture are driven by profit instead of need. (Altieri & Rosset, 1999)

W. J. Brill (1985) even argues genetic engineering will make well-characterized and specific modifications, thus there does not seem to be any reason to expect greater problems arising from recombinant organisms in agriculture than from produced through traditional practices. Some major disadvantages of genetically engineered crops are disregarded though. There is great concern among scientists regarding the environmental risks. (Paoletti & Pimentel, 1996)The release of genetically engineered organisms might affect biodiversity in both the tropics and temperate climates. (Paoletti & Pimentel, 1996)Another concern is that the organisms could 'self-perpetuate' and spread, which could make it very hard to control the species. (Brill, 1985)'Biotechnology promotes single gene solutions for problems derived from ecologically unstable monoculture systems designed on industrial models of efficiency'(See figure 1). (Altieri, 2004)Agricultural problems are perceived as genetic deficiencies of organisms and nature is treated as a commodity, while farmers are being more and more dependent on the industrial agriculture sector that increasingly concentrates power over the food system (See figure 1). (Altieri, 2004)

This power is mostly generated by the ownership of patents (see figure 1). A patent is a government-granted right to prevent other people or companies from making, selling, or using a product or process that you have invented. (Savich, 2007) In 1980, the U.S. Supreme Court ruled that genetically engineered (or modified) microorganisms are patentable. (Kimbrell, 2002) This meant that for the first time, life forms could be patented. (Kimbrell, 2002) This ruling was very beneficial to agricultural corporations but farmers were disadvantaged, because another law, the 1991 Act of the Union for the

Protection of New Varieties of Plants (UPOV), does not mandate an exemption on patents allowing farmers to use farm-saved seed freely as further planting material. (Lemley, 2001) Seed can thus not be used freely for cross-breeding anymore and this way, farmers are losing the right to use and develop diversity. (Lemley, 2001) As farmers cannot contribute to the plant gene pool anymore, agricultural homogeneity will grow (See figure 1). (Lemley, 2001) This makes the need to challenge the patent system, which not only provides multinational corporations with the right to seize and patent genetically engineered crops, but also 'accelerates the rate at which market forces already encourage monoculture cropping with genetically uniform transgenic varieties.' (Altieri, 2000)And because mixed plantings in which diverse cultivates are grown with other crops usually develop only moderate losses compared to monoculture situations (R. Ploetz, 2015), food security could be threatened (See figure 1).

Hence, the following causal model can be derived:

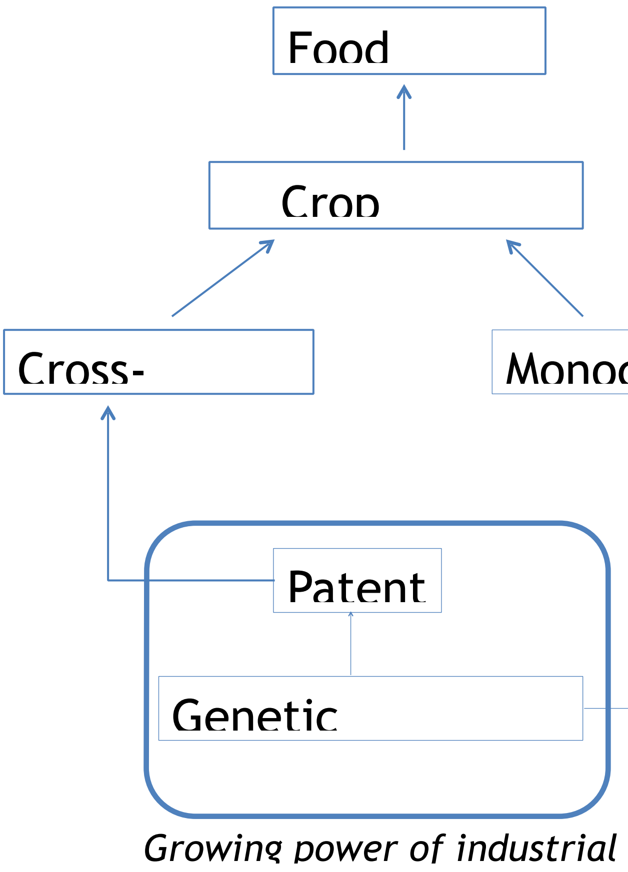


Figure 1: Conceptual model

Model description

Genetic engineering makes patenting possible. Through genetic engineering a certain trait in a crop can be created, which can in turn be patented. By issuing a lot of patents, industrial agricultural corporations are gaining more control over the seed (and thus food) market, making farmers more dependent on the industrial sector, thus increasing their power. Patents prevents farmers from using seed freely and forms a barrier for cross-breeding. This has, in turn, a negative influence on crop diversity, because of the decline in contribution to the gene pool.

Genetic engineering as a whole promotes single gene solutions and genetically engineered crops could spread very fast and endanger biodiversity, causing monocultures to exist. Monocultures are widespread production of a single crop (Shipton, 1977) which automatically means a lack of crop diversity.

The decrease of crop diversity, caused by both a decrease of cross-breeding and an the increasing existence of monocultures, means a reduction of the available amount and varieties of food. Thus, the access and availability to food are limited and food security is threatened.

3. Method of approach

To answer the research question 'To what extent does genetic engineering influence the existence of monocultures?' it is important to understand the concepts in the research question first. The dependent variable 'Monoculture' is defined as 'the practice of cultivation of the same crop in the same soil year after year'. (Shipton, 1977) Genetic engineering (also referred to as genetic modification) can be defined as 'Deliberate modification of the characteristics of an organism by the manipulation of its genetic material.' (Vanloqueren & Baret, 2009)

To get a clear picture of the factors or causes that play a role in the existence of monocultures, the idea of Hoogerwerf (1990) will be used. In his article about the reconstruction of policy theory about the drafting of a causal model. He follows certain steps to create this model for a policy theory, which involves for example the gathering of information about the concerning policy and its cause-effect relations. (Hoogerwerf, 1990) I will use this idea to map the causal relations in a case study and present a causal model.

The case study that will be discussed is that of the Panama disease (Fusarium wilt). Based on its history in export production, Panama disease is undoubtedly one of the most destructive plant diseases in modern times. (Ploetz, 2000) It is mainly found in the tropics and affects the banana. (Ploetz, 2000) A monoculture of one banana cultivate called 'Gros Michel' existed but was very susceptible to the disease. Most banana plantations in Costa Rica and Panama were affected and destroyed. A solution to the disease was found in genetically engineering the banana to be resistant to Fusarium wilt. This cultivate, called 'Cavendish', became the only one fit for production and soon became an even more widespread monoculture than 'Gros Michel'. (Ploetz, 2000)This case is very relevant for this research, because it concerns both variables in the research question. A monoculture is present, which renders it possible to do a literature study on its causes. The influence of genetic modification can be discussed as well, by looking at the effects it had on the existence of the Cavendish monoculture. This will give a clear image of the extent of the influence genetic modification has and if this is the main cause of if perhaps other factors are more important. Other possible cases may contain these elements as well, but Panama disease is still an important subject because a new strain of the disease was discovered and is currently spreading across parts of Asia and the Middle East. (Ploetz, 2015)

The analysis of the cause-effect relations regarding the case will be done using the following steps:

1. A short introduction to the case.
2. Presentation of all causes for the existence of the 'Gros Michel' monoculture found in literature.
3. Explanation on why this monoculture was eventually abandoned and what caused genetic engineering to emerge.
4. Discussion of the influence of genetic engineering on the Cavendish monoculture.

The mapping of causal relations will lead to the presentation of a causal model in the results. This will clarify the links between the causes and give an overview on the most important causes and the role of genetic engineering.

From the case analysis can be concluded what the main causes for the existence of monocultures are and to what extent genetic engineering is important. Based on this conclusion, I will make a recommendation for the future based on a possible solution, derived from literature.

Data was obtained through a literature study. Peer-reviewed articles, books and reports were found by using search engines Google Scholar, Scopus and LexisNexis Academic. The concepts that were searched on are: Genetic modification, genetic engineering, industrial agriculture, food security, crop diversity, Panama disease, banana disease, monoculture, genetic engineering and monocultures, seed technology, crop monocultures, monoculture in agriculture.

4. Case study: Panama disease

4.1 Short introduction to the case

The banana is arguably the most important fruit crop in the world and the most important agricultural product in the tropics, where over 100 million metric tons of fruit are produced annually. (Ploetz, 2005; R. Ploetz, 2015) Prior to the 1960s, the export trade in South America was based almost entirely on the 'Gros Michel' cultivate. This cultivate however, was highly susceptible to Panama disease.

4.2 Causes for the existence of the 'Gros Michel' monoculture

The following paragraphs will contain a description of the main causes for the existence of the 'Gros Michel' monoculture. The causes are divided into four sub-groups that can be seen as the major premises: Local conditions, crop characteristics, change in infrastructure and economical changes.

Local conditions

Early banana plantations were located in rainforests and planted on their well-drained, fertile soils which were mostly found in the tropical lands of Central America. (Ploetz, 2005)The climate conditions were also very favorable for the banana. The fruit thrives best with high temperatures and high humidity, which cause the rate of leaf production to increase significantly. (Turner, 1971) This makes tropical regions ideal for banana production. The initial American land base contained some of the finest banana lands in the world. (Marquardt, 2001) The lands were close to the mountains, with largely volcanic origins, where rivers plunged from, carrying deposits rich in phosphates and magnesium. (Marquardt, 2001)The soils supported complex forests that had a constant rain supply, which caused a 'leach of nutrients left by siltation and forest decay.' (Marquardt, 2001) This made the lands very fertile and suited for the production of exportable bananas. (Marquardt, 2001)

Crop characteristics

According to Steve Marquardt (2001) the banana had 'distinct advantages as an agro-industrial commodity.' One acre of banana plants produces large volumes of fruit all year round, which makes the fruit very appealing for production on a larger scale. (Marquardt, 2001) Trade became highly dependent on the 'Gros Michel' cultivate because it is in many ways ideal for export. 'Gros Michel' produces large, flavorful fruit and does not bruise easily, making it possible to ship the banana while keeping it intact. (Ploetz, 2005)

Change in infrastructure

In the early 1800s export of bananas began from the Caribbean. This export was done with sailing ships that were not made to carry heavy loads and were quite slow. Fruit was moved from the field to the ports by hand or horse, since railroads did not exist yet. (Ploetz, 2005) The conditions on the plantations slowly improved because roads were added, railroads were built and sailing ships were replaced by more reliable steam ships. (Ploetz, 2005)

The improvement of the infrastructure made transport easier and in 1896 bananas were shipped to a country other than the U.S. for the first time. Large-scale production occurred and new, overseas markets developed. (Ploetz, 2005) Fruit quantity and quality increased and prices decreased, changing the banana from a luxury to 'the poor man's fruit' (Ploetz, 2005) while more and more land came into bearing. (Marquardt, 2001)

Economical changes

Because of the perishability of the banana however, harvests needed to be timed perfectly and transported quickly to other countries; the perfect circumstances for the foundation of the United Fruit Company (UFCo) in 1899, owned by the U.S. (Marquardt, 2001) This transnational company's goal was the mass production and consumption of bananas and the UFCo used the appearance of Panama disease as a justification for closing old operations and opening new ones. (Marquardt, 2001) They united capital, shipping networks, lands and railroads to capitalize market development on a large scale. (Marquardt, 2001) Production sites were scattered to ensure a certain amount of fruit and by doing this, territory was gained quickly. The 'Gros Michel' cultivate was the standard banana produced for trade by the UFCo. (Marquardt, 2001) The use of this monoculture (the same cultivate was replanted year after year in the same soils) was a standard practice of the export trades in Central America (Ploetz, 2000) as there was no knowledge of the fact that monocultures are much more susceptible to diseases than mixed plantings (Ploetz, 2015) and the UFCo was not involved in the supervision of agricultural practices. (Marquardt, 2001) Meanwhile, the gain in territory of the UFCo meant an even bigger spread of the 'Gros Michel' monoculture (Ploetz, 2000)and increasing vulnerability, because the nutritious banana was so highly demanded in foreign countries, that de economy became largely dependent on the export of the monoculture. (Ploetz, 2000)

What is also important to consider, is that the large investments made by the United Fruit Company resulted in resilience to the idea of planting other banana varieties than 'Gros Michel'. (Marquardt, 2001) The U.S. market was judged to be inflexible and the UFCo did not give consideration to planting other banana varieties until the late 1950s. (Marquardt, 2001)

4.3. Abandonment of 'Gros Michel' and genetic engineering

In Costa Rica and Panama the banana disease struck early. In the Bocas del Toro region a big outbreak had resulted in the abandonment of 8000 hectares each by 1910. (Marquardt, 2001) Panama kept export levels ahead of the disease for a while, but by the late 1920s Panama's Atlantic production had ceased and Costa Rican exports declined fast. (Marquardt, 2001) By 1950, Fusarium wilt had spread to almost every banana-producing region in Central America, resulting in severe losses: "In the Ulua Valley of Honduras alone, 30.000 hectares were lost between 1940 and 1960." (Ploetz, 2000)

The quickly spreading disease destroyed harvests and proved 'Gros Michel' was very susceptible to it. (Ploetz, 2000) In any case, tropical agro-ecosystems are especially vulnerable to disease, since, unlike temperate zone cultivates, tropical crops have evolved in relatively stable, infrequently disturbed environments, and have developed little resistance to environmental changes like the eruption of a new fungal pathogen. (Marquardt, 2001) But high susceptibility was not the only reason 'Gros Michel' was abandoned.

Site selection for plantations was intuitive rather than scientific and most managers of banana plantations did not know what they were doing and did not protect the plants very well. (Marquardt, 2001) Until the mid-1920s, installation drainage was minimal and only done with tools used by hand and maintenance of the crop was limited mostly to drainage ditches, digging and removing unwanted stalks. (Marquardt, 2001) The United Fruit Company was not involved in the supervision of agricultural practices, so no action was taken to contain the disease. (Marquardt, 2001) Plantations were abandoned in the face of declining yields, because as the disease spread, the life expectancy of a plantation dropped from around fifteen years to less than five. (Marquardt, 2001) Different approaches to disease management were taken, such as adding minerals to the soils or using organic fertilizers, but none of the attempts to control the disease had any effect. (Marquardt, 2001) Even the discovery of an infectious agent did not lead to a cure. (Marquardt, 2001)

A solution was desperately needed to save the banana export. Plant scientists did research on the banana plant but unfortunately, breeding was beyond their abilities because edible bananas are by definition sterile. (Marquardt, 2001) The only solution was to start cultivating a different type of banana, but this seemed impossible because Fusarium wilt many of the different types that are grown. (Ploetz(2), 2005) The scientists began researching resistant strains to create a resistant banana cultivate and by the second half of the 1900s a genetically transformed (engineered) resistant cultivate was created, called 'Cavendish'. (Becker, Bugdale, Smith, Harding, & Dale, 2000)

4.4. Genetic engineering and the 'Cavendish' monoculture.

Because there was no other possible way to contain Panama disease, banana producing regions had no choice but to convert to the ‘Cavendish’ cultivate to save export. (Ploetz, 2000) In the infected soils of Central America, the production of resistant cultivars has been the only consistently effective tool to manage the disease. (R. Ploetz, 2015) The ‘Cavendish’ cultivate was soon produced everywhere and thrived in the infected soils where ‘Gros Michel’ was wiped out. Because Panama disease affected every banana cultivar in the tropics (Ploetz(2), 2005), ‘Gros Michel’ and other banana cultivars were replaced by ‘Cavendish’ entirely, replacing the ‘Gros Michel’ monoculture with an even bigger ‘Cavendish’ monoculture.

5. Results

Two causal models can be drafted to summarize the causes for the existence of both the 'Gros Michel' and the 'Cavendish' monoculture, based on the literature on the case study discussed in chapter 4. The causes for the different monocultures are presented in separate models to make a distinction between the situation where genetic engineering did and did not have influence.

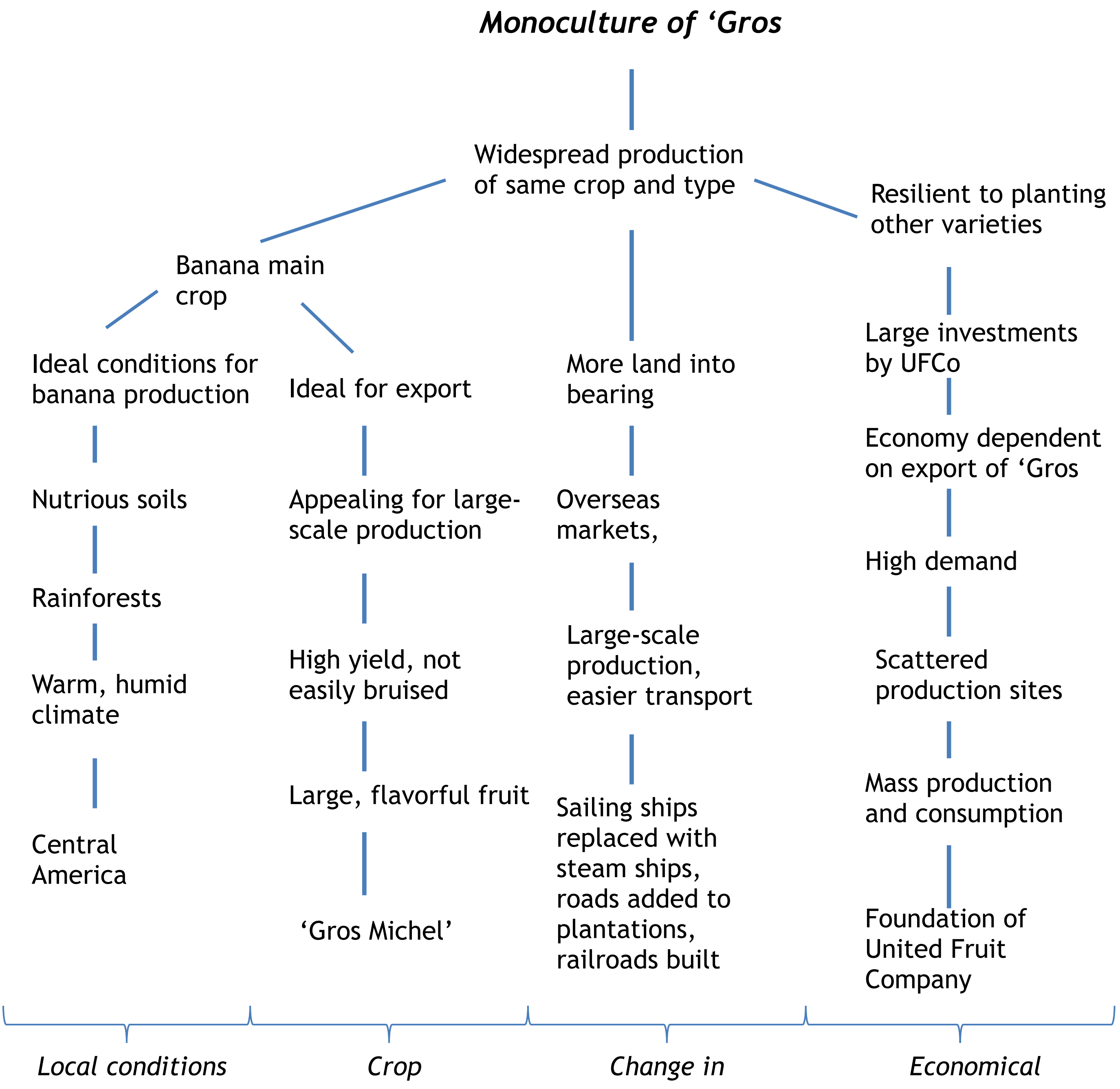


Figure 2: Causal model for the 'Gros Michel' monoculture

As is shown in the causal model above (See figure 2), there are many causes for the monoculture existence of 'Gros Michel', under the headings 'Local conditions', 'Crop characteristics', 'Change in infrastructure' and 'Economical changes'. They all eventually cause the widespread production of the same crop and same crop type, meaning a monoculture has come to exist. For the existence of the 'Cavendish' monoculture, the following causal model was drafted:

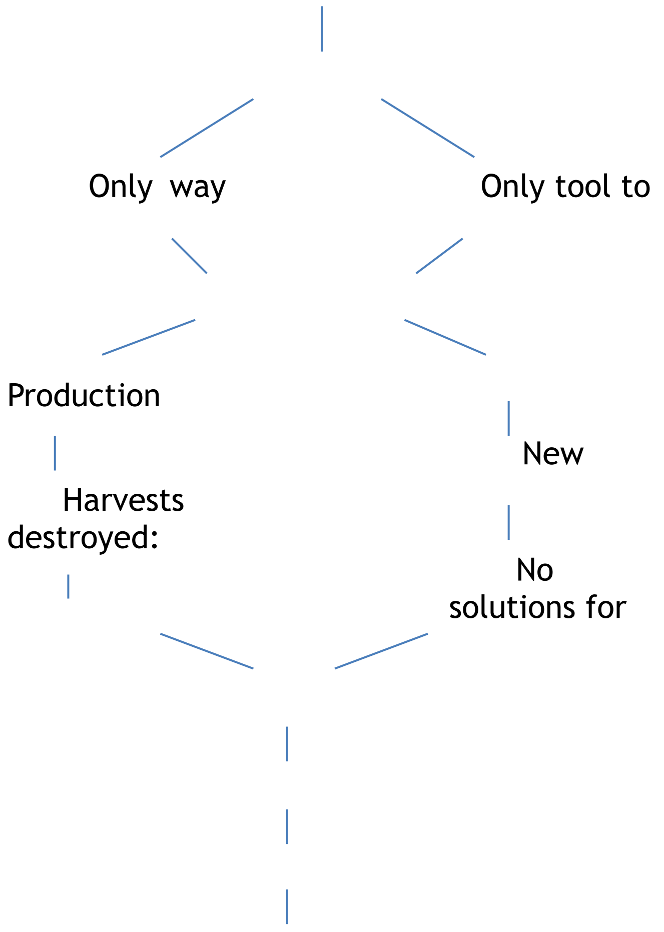


Figure 3: Causal model for the 'Cavendish' monoculture

From this model (See figure 3) can be concluded that economical circumstances played a role in the downfall of the banana plantations. The United Fruit Company did not recruit managers who knew what they were doing and was not involved in maintenance of the plantations. The bad maintenance made the plantations vulnerable, so when the Panama disease struck, the disease spread fast and destroyed harvests. Production was ceased and together with the severe losses, this resulted in a decline in export. When the resistant 'Cavendish' cultivar was engineered, it was the only way to save exports (and the economy) so it was eagerly accepted. Panama disease was so devastating, that scientists failed to find solutions to control it other than the switch in production to a new variety. They discovered that breeding was impossible, because the bananas had to be edible for export to be maintained and edible cultivars were by definition sterile. Genetically engineered resistance was the only tool to create an edible banana cultivar and to manage Fusarium wilt. The genetically engineered 'Cavendish' soon replaced 'Gros Michel' and other banana cultivars, because this was the only option. A new monoculture of 'Cavendish' bananas was created, which was even more widespread than the 'Gros Michel' one.

Genetic engineering can be seen as a major solution to the problem of plant disease management. It can influence the existence of a monoculture in a way that it can be the 'only way out'. It was a necessary evil, exchanging crop diversity for export production. Many different causes, however, had influence on the existence of a monoculture in the first place, economical changes proving to be the most important causes, as economical change can be seen as a condition for change in infrastructure. Without the foundation of the United Fruit Company and the growing export market, 'Gros Michel' would have never become such a widespread monoculture and would maybe have not been as vulnerable to Fusarium wilt as it was now.

6. Discussion

I have chosen to use one case study to analyze the main causes for the existence of a crop monoculture. Due to time limits, I did not use a second case as comparison, which could have been used to check the results found from case study of Panama disease. It is possible other causes for monoculture existence would be found in other case studies or different situations, but monoculture existence in crops is comparable to the rest of the world, as monocultures can arise everywhere. That is why the results of this case study can be generalized.

The case study of Panama disease is important because the creation of a resistant cultivar has not been a permanent solution. A new type of Panama disease, TR4, is spreading and if this reaches the main export countries in Central America, it could lead to severe losses and maybe even the extinction of the banana species. Preventing further outbreaks of TR4 requires better understanding of its long-distance dissemination. (R. Ploetz, 2015) As there is no possible solution for this problem now (R. Ploetz, 2015), studies of the disease should continue, directed at finding other ways to manage Fusarium wilt and prevent a further spread to the tropics.

Lessons should be learned from the banana case regarding management of crop plantations and preventing plant diseases and the influence of economical factors should be taken seriously.

7. Conclusion

After discussing the different causes for monoculture existence in the case of Panama disease, an answer to the research question 'To what extent does genetic engineering influence the existence of monocultures?' can be given:

Monocultures can develop under different circumstances, having different causes. In the case of Panama disease, the main causes for monoculture existence were local conditions, crop characteristics, change in infrastructure, and most important, economical changes. Plant disease was the main cause of the need for genetic engineering. Having no choice but to use a resistant cultivar for disease management, the monoculture changed from 'Gros Michel' to 'Cavendish' and became even more widespread. In conclusion, genetic engineering can have a strengthening role in monoculture existence, but is not the main cause.

Future research should be done to prevent monocultures in the future and reducing disease susceptibility. Creating a resistant cultivar can be a temporary solution but in the long run, new types of diseases can develop and destruct the resistant type as well, leaving decreased diversity and increase losses. Because it was proven mixtures generate fewer losses than single crop plantations, a possible solution could maybe found in crop rotation, using mixtures of plantings instead of only one type. This solution would have to be further researched and possibly tested in the field before implementation. Farmers would then have to be given the power to control their planting methods and materials by restricting the amount and reach of patents, reducing the power of industrial agriculture and preventing monoculture cropping systems.

Bibliography

Altieri, M. A. (2000). The Ecological impacts of transgenic Crops on Agroecosystem Health. *Ecosystem Health, 6*(1), 13-23.

Altieri, M. A. (2004). *Genetic Engineering in Agriculture*. Canada: Food First Books.

Altieri, M. A., & Rosset, P. (1999). Ten Reasons Why Biotechnology Will Not Ensure Food Security, Protect the Environment, And Reduce Poverty In The Developing World. *AgBioForum, 2*(3&4), 155-162.

Becker, D. K., Bugdale, B., Smith, M. K., Harding, R. M., & Dale, J. L. (2000). Genetic transformation of Cavendish banana (Musa spp. AAA group) cv 'Grand Nain' via microprojectile bombardment. *Plant Cell reports*, 229-234.

Brill, W. J. (1985). Safety concerns and genetic engineering in agriculture. *Science, 227*(4685), 381-384.

Garcia, M. A., & Altieri, M. A. (2005). Transgenic Crops: Implications for Biodiversity and Sustainable Agriculture. *Technology & Society, 25*(4), 335-353.

Hoogerwerf, A. (1990). Reconstructing Policy Theory. *Evaluation and Program Planning*, 285-291.

Kimbrell, A. (2002). *The Fatal Harvest Reader: The Tragedy of Industrial Agriculture*. Islad Press.

Lemley, M. (2001). The Growing Complexity of the United States Patent System. *Boalt Working Papers in Public Law*.

Marquardt, S. (2001). 'Green Havoc': Panama Disease, Environmental Change, and Labor Process in the Central American Banana Industry. *The American Historical Review*, 49-80.

Paoletti, M. G., & Pimentel, D. (1996). Genetic Engineering in Agriculture and the Environment. *BioScience, 46*(9), 665-673.

Pinstrup-Andersen, P. (2009). Food security: definition and measurement. *Food security*, 5-7.

Ploetz(2), R. C. (2005). *Panama disease: An Old Nemesis rears its Ugly Head, Part 2. The Cavendish Era and Beyond*. St. Paul: American Phytopathological Society.

Ploetz, R. C. (2000). Panama Disease: A Classic and Destructive Disease of Banana. *Plant Health Progress*.

Ploetz, R. C. (2005). *Panama Disease: An Old Nemisis Rears its Ugly Head, Part 1. The Beginnings of the Banana Export Trades*. St. Paul: American Phytopathological Society.

R. Ploetz, S. F.-A. (2015). Tropical race 4 of Panama disease in the Middle East. *Phytoparasitica*.

Savich, J. (2007). Monsanto v. Scruggs: The Negative Impact of Patent Exhaustion on Self-Replicating Technology. *Berkeley Technology Law Journal*.

Shipton, P. (1977). Monoculture and soilborne plant pathogens. *Annual Review Phytopathology*, 387-407.

Turner, D. (1971). Effects of Climate on Rate of Banana Leaf Production. *Tropical Agriculture*, 283-287.

Vanloqueren, G., & Baret, P. V. (2009). How agricultural research systems shape a technological regime that develops genetic egieerig but locks out agroecological innovations. *Elsevier*, 971-983.

Zhu, Y., Chen, H., Fan, J., Wang, Y., Li, Y., Chen, J., . . . Mundt, C. C. (2000). Genetic diversity and disease control in rice. *Nature, 406*, 718-722.