DETERMINANTS OF DROUGHT ADAPTATION AMONG FIELD VEGETABLE GROWERS IN FLORIDA AND LIMBURG

By

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To my friends and family

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LIST OF ABBREVIATIONS

AC	Adaptive Capacity
afy	acre-foot per year
ASR	Aquifer Storage and Recovery
AWEP	Agricultural Water Enhancement Program
bgd	billion gallons per day
BMP	Best Management Practice
CUP	Consumptive Use Permit
CWU	Consumptive Water Use
DAM	Drought Adaptation Measure
EC	European Commission
EQIP	Environmental Quality Incentives Program
ERP	Environmental Resource Permit
EUT	Expected Utility Theory
F.A.C.	Florida Administrative Code
FDACS	Florida Department of Agricultural and Consumer Services
FDEP	Florida Department of Environmental Protection
F.S.	Florida Statutes
GDP	Gross Domestic Product
GGOR	Desired Ground- and Surface Water Regime
Gdp	gallons per day
IFAS	Institute of Food and Agricultural Sciences
IPCC	Intergovernmental Panel on Climate Change
KNMI	Royal Dutch Meteorological Institute
mgd	million gallons per day

MIL	Mobile Irrigation Laboratory
NASS	National Agricultural Statistics Service
NRCS	Natural Resources Conservation Service
O&M	Operation & Management
RWA	Regional Water Authority
TAM	Technology Acceptance Model
US	United States
USDA	United States Department of Agriculture
USGS	U.S. Geological Survey
WCM	Water Conservation Measure
WFD	Water Framework Directive
WLSAD	Water Level Steered Agricultural Drainage
WMD	Water Management District
WP_{IR}	Water Productivity of the Irrigation System

Abstract of Thesis Presented to the Graduate School
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This thesis outlines the factors that influence the adoption of drought adaptation measures among field vegetable farmers in Florida and Limburg. The survey results analysis indicates that grower, farm, spatial and institutional characteristics, as well as the perceived attributes of measures, influence adoption. However, the effects depend on the type of measure. Risk adversity often positively influenced the probability of adoption. The main barriers to adopting micro-irrigation include the perceived negative cost-benefit ratio, the initial installation costs, and the time it is expected to cost. For some growers using micro-irrigation, Jevons' paradox in water use may exist.

To increase adoption of drought adaptation measures policymakers could target older farmers, who are currently less likely to adopt sensor technology. Moreover, growers who have been asked to cutback water use, and who are thus probably located in a relatively water scarce area, were less likely to adopt measures. Therefore, targeting growers in these areas might lead to increased adoption rates, depending on the reasons for growers not to be adopting now. Cost-share programs aiming to increase adoption were overall not shown to be a positive significant influence on the likelihood to adopt. This indicates that people may adopt measures without using the

support programs in place. The negative relationship between cost-share enrollment and adoption of sensor technology could mean that growers enrolled in a cost-share program use technologies that function as substitutes for sensors. A more elaborate dataset would allow for analysis of this hypothesis.

CHAPTER 1
INTRODUCTION

1.1 Background

Due to a growing world population and increasing incomes the demand for the world's available freshwater resources is on the rise. Demand is especially high in densely populated areas such as Florida and the Netherlands, which are the focus areas of this study. The Netherlands has one of the highest population densities in the world and Florida is close to becoming the third most populous state in the United States (U.S.). Both regions face increasing competition for different water uses such as residential consumption, irrigated agriculture and natural areas that are crucial for the survival of rare plant and animal species.

Agriculture is important in both Florida and the Netherlands. Florida is the second leading U.S. state in area and dollar value of vegetable crop cultivation with 201,000 acres planted in 2012 and a crop value greater than $1.1 billion (USDA NASS, 2013). In the Netherlands field vegetable production is also an important sector, with a value of €422 million ($497 million) in 2012 (Product Board for Horticulture, 2013).[1]

Both Florida and the Netherlands regularly experience drought. The exact drought frequency depends on the drought definition used.[2] In this study we follow the most common definition (also called meteorological drought) which links drought to reduced precipitation levels and increased temperatures over some specified period of

[1] More general, in 2012 the Dutch agricultural sector, excluding processing industries, created jobs equal to 161,000 years of employment, accounted for 1.5% of the Gross Domestic Product (GDP), and was the largest land user (LEI and CBS, 2012).

[2] For an overview of over 150 definitions of drought, see Wilhite and Glantz (1985).

time relative to a regional baseline condition.[3] The precipitation deficit, i.e. the difference between precipitation and evapotranspiration (the sum of evaporation and plant transpiration), is often used as a measure for meteorological drought. The Netherlands regularly experiences such precipitation deficits, e.g. in the summers of 2003 and 2006, causing substantial crop losses in the agricultural sector. According to the Dutch Meteorological Institute (in Dutch: KNMI) the spring of 2011 was the driest ever recorded in the Netherlands in terms of precipitation deficit (KNMI, 2011a).

Other definitions link drought to a deficiency in surface and subsurface water availability or a lack of sufficient soil moisture to support crop growth. These deficiencies, however, also depend on how much water was stored in the region or on the farm due to antecedent conditions, and on socioeconomic aspects such as water demand. The Florida Department of Environmental Protection (FDEP) includes these aspects in their definition of drought as a period of unusually dry weather that persists long enough to cause serious problems such as crop damage and/or water supply shortages (FDEP, 2013a). Following this definition, despite access to coastal, river, and lake water, Florida has experienced at least one severe and widespread drought every decade since 1900, and records indicate that 2006 and 2007 were the driest years Florida has experienced since 1932 (*Ibid*).

Climate change projections for both regions show that meteorological droughts will occur more often in the future. KNMI has developed four climate scenarios for the Netherlands for 2050 and 2100 based on climate models, socioeconomic scenarios,

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[3] The regional baseline can be calculated with historic data. However, a decision has to be taken on what variance from the average, and over what period of time, is sufficient to label a precipitation deficiency as a drought. Also, it is necessary to look far back into the past to be able to adequately capture a regional climate (Wilhite and Glantz, 1985).

and historical measurement records. They all predict more occurrences of extreme drought in the future (KNMI, 2006; Hurk *et al*., 2006). In the driest KNMI scenario (W+, see Figure 1-1) the precipitation deficit increases from the current average of 100 mm per summer to 200 mm in 2050 and to 440 mm in 2100 (Beek *et al*., 2008). According to the Dutch Delta Committee climate change will also lead to decreased summer river discharge and increased saltwater intrusion (Deltacommissie, 2008).[4]

In Florida increasing temperatures and occurrence of extreme events may also increase problems with water availability (Karl, Melillo and Peterson, 2009). Moreover, Florida's climate is influenced by the El Niño/La Niña–Southern Oscillation phenomenon.[5] In a La Niña year the winter, an important vegetable production season in Florida, tends to be warmer and drier, although the phenomenon is hard to predict.

Combining these pressures with the predicted impacts of population growth and pollution, the water supply in Florida and the Netherlands is likely to encounter difficulties in sustaining current water needs at all times (Pimentel *et al*., 2004; Rijsberman, 2006; FDEP, 2011).[6] The current water supply strategies for Florida and the Netherlands are therefore said not to be climate-proof in the long-run and are in need of further development.

[4] This is a committee that was asked to come up with recommendations on how to protect the Netherlands against the consequences of climate change (Deltacommissie, 2008).

[5] This is a climate pattern caused by warm ocean water temperatures off the west coast of South America. The extremes of the oscillations can cause extreme weather such as droughts in many regions of the world including Florida.

[6] By 2030, Florida's demand for fresh water is estimated to increase by about 1.9 billion gallons per day (bgd) to a total of 8.2bgd, and traditional sources of fresh groundwater are not expected to be able to meet the additional demand (FDEP, 2011).

Agriculture thus faces the challenge of producing valuable food for a growing world population under increasing scarcity of water resources.[7] Droughts often lead to water use restrictions and crop losses, especially among farmers who do not use supplemental irrigation.[8] Moreover, in both Florida and the Netherlands the main agricultural production season coincides with the driest part of the year. Additionally, in the Netherlands irrigated agriculture has the lowest priority when there is a water shortage.[9]

It is therefore important to look for ways to reduce agricultural drought vulnerability. This might not be an easy task. As Figure 1-2 shows in both Florida and the eastern part of the Netherlands sandy soils are prevalent. Sandy soils have a relatively low water-holding capacity and are thus more prone to low soil moisture in periods of drought.

Some growers in Florida and the Netherlands reduce their drought vulnerability by using supplemental irrigation. However, the sources of irrigation water are potentially affected by drought too. Growers who rely on groundwater sources are generally less susceptible to the effects of meteorological drought than growers who use surface water, as groundwater levels are less correlated with rainfall (Allaire, 2009).

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[7] However, higher temperatures might advance the start of the growing season. Also, agricultural acreage in the Netherlands is projected to decrease by 0.3 percent per year (Silvis *et al*., 2009). If this reduction occurs in drought-prone areas or enlarges the area available for water buffering, this could have positive effects on freshwater availability for other farmers.

[8] It is important to note that the income effects of drought are not necessarily negative. If a farm experiences crop losses but does relatively well compared to other producers, and if the drought-affected producers supply a substantial share of the market, then the price mechanism can even lead to a situation where a farmer has a higher income than otherwise due to the higher prices caused by scarcity on the markets.

[9] This is specified in the water distribution priority sequence ('Verdringingsreeks'), a list that prioritizes water distribution in a water consumption hierarchy.

Florida has the largest irrigated agricultural acreage of the southeastern United States. Agriculture accounted for 34% of Florida's fresh groundwater withdrawals and 52% of fresh surface water withdrawals in 2010 (USGS, 2013). Figure 1-3 A shows on a map the percentage of agricultural land that is irrigated in the Netherlands. This figure bears a resemblance to Figure 1-3 B, which shows where production of field vegetables is concentrated in the Netherlands. There is a noticeable concentration of field vegetable production and irrigated acreage (over 60 percent) in the southeast of the Netherlands.

This area is located in the Dutch provinces of Limburg and North-Brabant and is part of an area called the High Sandy Soils. The main water source used in this region is groundwater. During dry periods, the groundwater levels in the deep sandy soils in this area can drop drastically and cause soil desiccation. At the same time, options for getting water from other areas are limited. Field vegetable growers in this area would benefit from measures that reduce their vulnerability to drought.

Recently the bottlenecks in freshwater supply due to climate change were mapped for different areas in the Netherlands. The sandy soils in the east part of the Netherlands were identified as a problematic area (Groffen, Verhagen and Wielinga, 2012). In 2005 a drought study concluded that in the province of Limburg the main adaptation options are to increase water retention and to increase irrigation (Versteeg, Klopstra and Kroon, 2005). Florida is in many ways similar to the High Sandy Soils in the east of the Netherlands and has a history of promoting drought adaptation measures (DAMs) such as irrigation and water retention measures.

1.2 Problem Statement

Implementing DAMs can be costly and technically difficult. Growers in Florida can apply for support programs available at the federal, state, and Water Management District (WMD) level. For example, as Figure 1-4 shows, Florida has a large number of water-related Environmental Quality Incentive Program (EQIP) contracts, which provide financial and technical assistance for implementation of certain DAMs. The resources expended for support programs ask for research to inform policymakers about the factors that influence adoption behavior, in order to design effective drought adaptation policies. This can also provide insights for the Netherlands. The main research question that this study tried to answer is:

"Which factors influence adoption of drought adaptation measures?"

It is also important to look at the effect of DAMs on total water use, as some studies have indicated that DAMs can inadvertently increase consumptive water use. For example, non-irrigating farmers can be adversely affected by large-scale irrigation if it dries up the streams that smaller farmers rely on (Bartels, Furmand and Royce, 2011). However, assessing agricultural water use is difficult. Pumpage data are limited and often imprecise, and some of the water withdrawn is returned to the hydrologic system. Also, changes in cropping patterns from year to year and between seasons, and the effects of weather patterns make determination of actual agricultural water consumption a challenging task. Our study includes a brief description of how growers indicate their water use has changed after adopting 'efficient' irrigation.

1.3 Study Areas

This section focuses on the study areas' locations and climates, as well as the irrigation systems and main water sources used for agriculture. It concludes with an overview of the crops grown in both areas.

1.3.1 Florida

Florida is a state in the southeast of the United States. Its location is shown in Figure 1-5. It is divided into a subtropical and a tropical climate. Average annual precipitation in Florida varies from 1,000 to 1,800 mm with a lot of variation within and between regions (NCDC, 2011). Most of this precipitation falls during the rainy season, which lasts from June through September. Towards the end of the dry season drought can become a problem for growers. The main harvest seasons in Florida occur in late fall, winter and spring when the Florida supply is sometimes the only one in the United States (Olson, 2011).

Average annual temperatures in Florida range from 65° to 70°F (18° to 21°C) in the north, and from 74° to 77°F (23° to 25°C) in the south. These temperatures indicate relatively high evaporation rates. Depending on the terrain, average annual potential evapotranspiration ranges from a low of 570 mm for pastureland with a deep water table to 1,340 mm in sawgrass marshes (USGS, 2012) and 1,500 mm for open-water locations. Evapotranspiration is a large part of the hydrologic 'budget' in Florida, ranging from 30 percent to over 100 percent of average precipitation.

Agricultural water withdrawals account for 40 percent of all water withdrawals in Florida, amounting to almost 2,770 million gallons per day (mgd). Forty-seven percent of agricultural freshwater withdrawals are from groundwater. Eight counties report daily freshwater withdrawals for agricultural irrigation of almost 100 mgd or more, with Palm

Beach (792 mgd) and Hendry (385 mgd) Counties being the largest users. Withdrawals for agricultural irrigation vary seasonally. They are usually higher at the end of the dry season (Marella, 2008).

1.3.2 Limburg

Limburg is one of twelve provinces of the Netherlands, a small country in western Europe. Its location is shown in Figure 1-6. The average daily temperature in Limburg ranges from 5°C (41°F) in January to 23°C (73.4°F) in July with an annual average temperature of 9.8°C (49.6°F). Average annual precipitation in Limburg is 739 mm with a lower bound of an average 700 mm in the center of the province. Not only is this rather low compared to the rest of the country, but also most rainfall occurs outside the main production season, i.e. from November until January. July and August are the months with the lowest rainfall. The province experiences precipitation deficits of up to 200 mm per year, with an average (between 1906 and 2000) of 144 mm. Climate change predictions forecast an increase in both the probability and the magnitude of precipitation deficits. This is also true for the scenario where the climate as a whole would become wetter, because in this scenario the rainfall becomes more extreme, and the soils may not be able to absorb the rainfall.

In 2012 there were 658 field vegetable growers in Limburg (CBS, 2013). About half of them grew field vegetables as their main crop, whereas other growers grew field vegetables as a secondary activity. There were also 2,293 arable vegetable producing farms in Limburg in 2012 (*Ibid.*). Table 1-1 shows that Florida and Limburg have production of several field vegetables in common. Numbers for Florida might be underestimated due to non-response error. There are different numbers of farms in both regions, mainly because Florida is much larger than Limburg. The original research plan was to focus on more areas in the Netherlands, but due to time and budget limitations we only focused on Limburg.

1.4 Objectives and Outline of this Thesis

The study had four main objectives. The first was to make a comparison of quantitative agricultural water policies in Florida and the Netherlands. Chapter two presents the overview of agricultural water policies in Florida and Limburg. The second objective was to give an overview of the merits and shortcomings of DAMs in Florida and the Netherlands. This is done in chapter three. This chapter also considers the concerns that have been expressed regarding the adverse effects of ‘more efficient’ irrigation systems, and describes the complexity of concepts such as ‘water use efficiency’. The third objective was to come up with a conceptual model to investigate the factors that influence adoption of DAMs among field vegetable growers in Florida and Limburg. Chapter four describes this model, which is based on the literature review. The fourth and final objective of the study was to test this model through analysis of survey data. The survey was sent to over 1,000 vegetable growers in Florida and 1,585 growers in Limburg. Chapter five describes the survey methodology, the empirical models used, and gives a summary of the data. Chapter six provides an analysis of the results. The results provide insight into the factors that influence farmers’ decisions to implement drought adaptation measures. We also provide summary statistics of the responses regarding the effect of converting to efficient irrigation on water use. Chapter seven describes the conclusions that can be drawn from this study, as well as its limitations and recommendations for future research.

Table 1-1. Numbers of farms and acreage of main field vegetables in Limburg and Florida.

	LIMBURG			FLORIDA		
	Number of farms	Hectares	Acres	Number of farms	Hectares	Acres
ARABLE VEGETABLES						
Sweet corn	14	64	158	385	16,034	39,622
Potatoes:	723			181	10,735	26,526
Seed potato	20	164	405			
Table potato	707	6,321	15,620			
Starch potato	4	16	40			
Kale	7	24	59	N	N	N
Onions:						
Seed onion	54	367	907			
Pearl onion	2	7	17			
Planting/table onion	23	116	287	22	9.7	24
Carrots:				23	611	1,509
Topped carrot	29	168	415			
Washed carrot	68	480	1,186			
Turnip				15	7	17
Spinach	30	0.5	1	17	12	30
Snap/spring beans	63	0.5	1	373	16,146	39,897
FIELD VEGETABLES						
Strawberries	82	396	979	212	2,668	6,594
Bunched carrot	6	25	62	23	611	1,509
Endives	2	22	54	N	N	N
Asparagus	377	1,750	4,324			
Cauliflower	39	162	400	11	C	C
Broccoli	11	55	136	52	C	C
Chinese cabbage	22	79	195	40	1,297	3,206
Brussels sprouts	12	60	148	1	C	C
Red cabbage	18	8	20	N	N	0
Head cabbage	14	12	30	81	3,973	9,817
White cabbage	27	63	156	N	N	0
Oxheart cabbage	17	20	49	N	N	0
Celery	5	9	22	3	C	C
Zucchini (z), pumpkin (p)	51	206	509	188 z 35 p	2,974 z 60 p	7,349 z 149 p
Leek	141	2,430	6,005	N	N	N
Lettuce	49	655	1,619	75	2,930	7,239
Rhubarb	55	0.5	1	1	C	C

Source: CBS (2013); USDA (2007).
Note: C stands for confidential; N stands for not included in the census or survey.

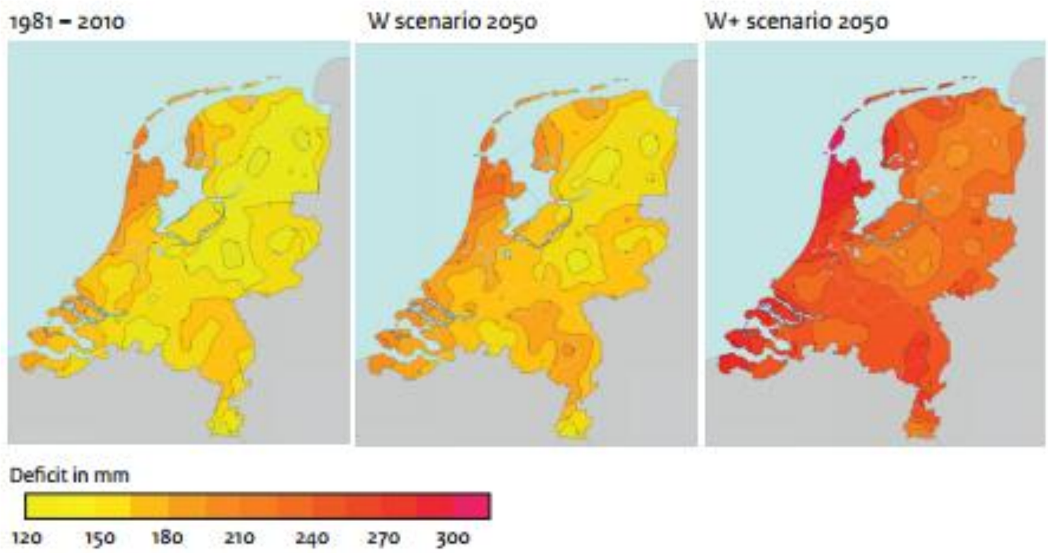
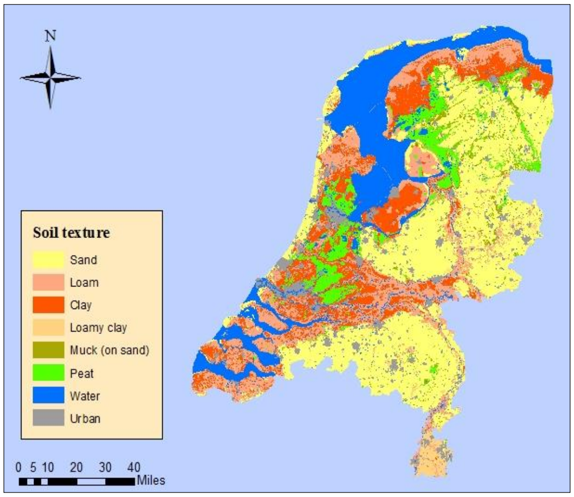
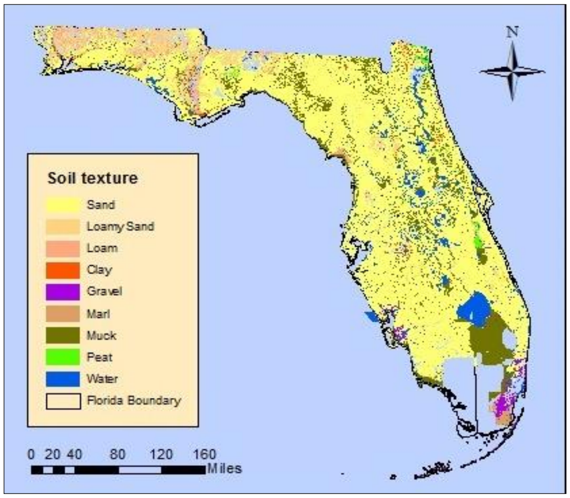


Figure 1-1. Maximum precipitation deficit per year under different scenarios. Source: KNMI (2011b) in Ligtvoet, Minnen and Franken (2013).

A




B

Figure 1-2. Main soil types in the Netherlands and Florida.
A) The Netherlands, B) Florida.
Source: Author. Data from WUR-Alterra (2006); USDA NRCS (2013).

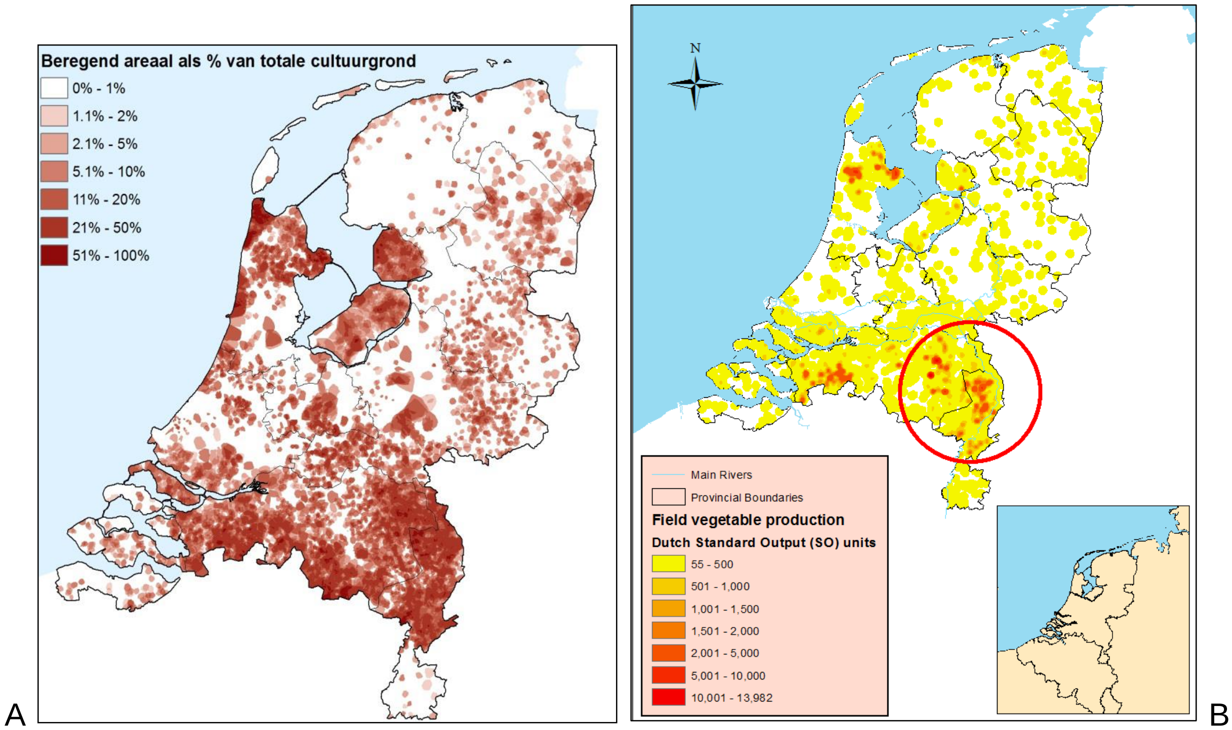


Figure 1-3. Agricultural land in the Netherlands
A) under irrigation, B) with field vegetable production. Source: Polman, Linderhof, Michels, Sandt and Vogelzang (2012); Author, using data from CBS (2013).

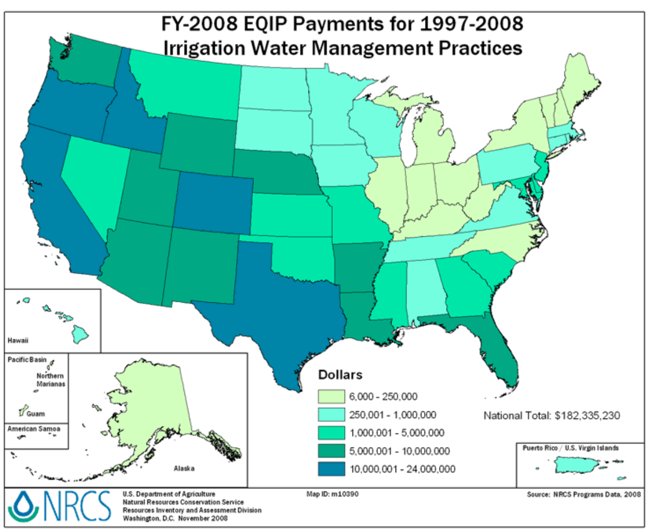


Figure 1-4. EQIP payments 1997-2008 for irrigation water management practices. Source: USDA NRCS (2013).

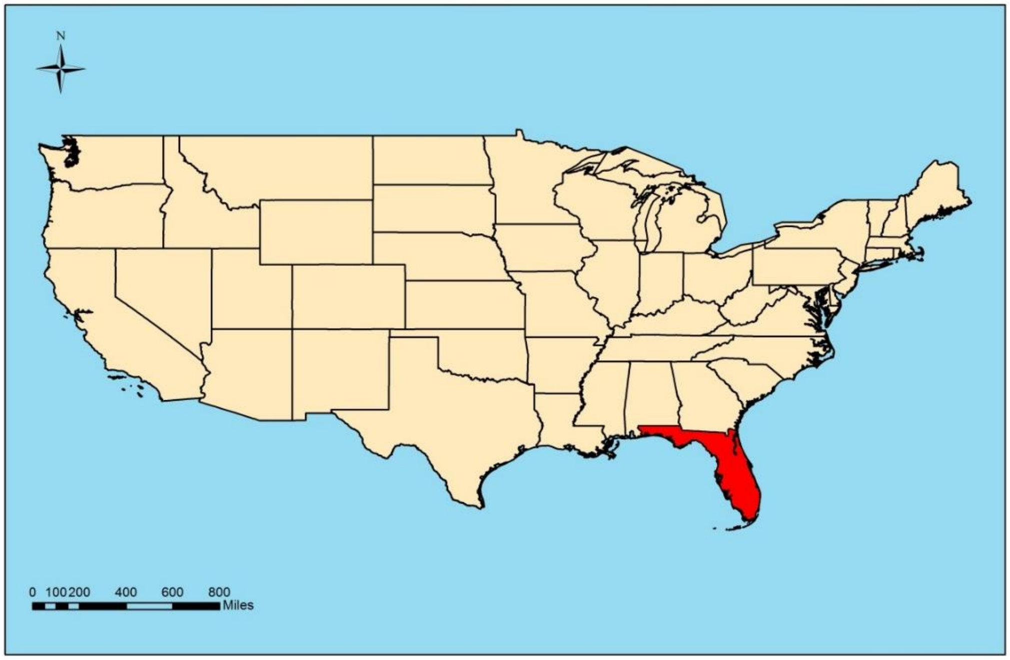


Figure 1-5. Location of Florida.
Source: Author, using data from USGS (2005).

Figure 1-6. Location of Limburg. Source: Author, using data from Geo Dataportaal Limburg (2013).

CHAPTER 2
WATER POLICY IN FLORIDA AND THE NETHERLANDS

2.1 Water Authorities and Laws

To understand drought adaptation behavior among vegetable growers in Florida and Limburg it is important to understand which water policies influence their water use practices. This chapter is based on literature review and interviews with water policy experts. It answers the following question:

"What water policies affect agricultural water extraction in Florida and Limburg?"

In order to give a complete response to this question the following three sub-questions are answered:

- Which water authorities and laws manage surface- and groundwater extractions?
- Do growers need to get a permit or register for surface- or groundwater use?

In answering this question we also looked at conditions for using water for irrigation, as well as special regulations during drought conditions, water charges and monitoring of water use.

- Are there support programs for farmers to encourage drought adaptation?

2.2 Water Authorities and Laws in Limburg and Florida

This section gives a brief overview of water management authorities and laws in the Netherlands and Florida that are relevant for agricultural freshwater extraction. The section includes a brief history of the property rights regimes related to agricultural use of freshwater.

2.2.1 Water Authorities and Laws in Limburg

Water management in the Netherlands has a long history, with many laws coming in and going out of practice, and with several levels of water authority. Although historically Dutch water policies tended to focus more on drainage and flood protection than on freshwater ownership and allocation, there has been a series of laws dealing with the latter. These laws will be described first, followed by an outline of the levels of water authority in the Netherlands that influence agricultural water use.

2.2.1.1 Water laws and property rights

The Dutch Civil Code (in Dutch: Burgerlijk Wetboek) of 1838 specified that the Dutch state owned the territorial seas, coastal waters, and public navigable rivers in the Netherlands unless they were owned by another public body. The Code also stated that property ownership could include ownership of groundwater, but only after the water had been extracted. Aquifers were thus not considered as private property. Likewise, the waterbed of a watercourse could be privately owned, but not the water flowing in it, except when the property completely encloses it, e.g. in a small pond (Kuks, 2002).

At that time, people were already using wells to extract groundwater, for which they had to apply for a license under the Nuisance Act. The license could be denied if the projected extraction was considered a nuisance. However, little was known about the effects of groundwater extraction. Commissions of experts were sometimes installed to investigate the consequences of the extractions (Pellenbarg, 1997).

Between the 1950s and the 1980s several laws were passed that redistributed water rights. A 1954 Act gave water supply companies water extraction rights, which had to be tolerated by the owners of land adjoining the water source. The latter could not use the Nuisance Act to object to these extractions, but they could request compensation in case of damage. However, in 1981 a Groundwater Act was passed which proclaimed that the interest of public water supply should not be treated differently from other interests in terms of water allocation. Extractors had to compensate those who had borne negative effects of their water extraction, such as farmers experiencing harvest losses due to lower groundwater levels. The Act also put provinces in charge of groundwater extraction and gave them power to collect groundwater extraction charges, which had to be used for antidesiccation measures (Kuks, 2002).

In the 1980s the environment became a recognized water user. A constitutional revision in 1983 enabled expropriation of property rights that posed a threat to the environment. Moreover, the 1989 Water Management Act made protection of ecosystems an official water management goal. This Act gave the regional water boards the authority to pass ordinances to regulate water uses (IJff, 1993). The Water Board Act of 1992 further enlarged this authority.

Also in 1992, the Civil Code of 1838 was revised. It officially changed the status of surface- and groundwater to a 'no property' that cannot be owned by a person or by the state but that belongs to society as a whole. Treating water as a 'no property' forces the state to protect water by public law (Kuks, 2002). This means, for example, that landowners experiencing adverse effects from someone else's groundwater extraction on their lands cannot use private law to do something about it. They do not own the water, and if the other extractor has a use permit the only thing the landowner can do is request compensation. To extract groundwater on privately owned land, the landowner needs to follow water extraction rules. Often there is a notification or permit requirement for water extraction.

2.2.1.2 Water authorities

The 2009 Water Act changed the division of water tasks among the parties involved in Dutch water management. There are now two main water authority levels in the Netherlands. At the national level the Ministry of Infrastructure and the

Environment initiates new policies and manages the main national waterways. The latter is executed by Rijkswaterstaat, which is the water engineering department taking care of all state waters and state water infrastructure, similar to the U.S. Army Corps of Engineers. At the regional level the Regional Water Authorities (RWAs) are in charge of day-to-day operational management of regional waterways and wastewater treatment.[1] The RWAs are also in charge of the main operational tasks related to groundwater management. They have their own statutes (in Dutch: 'Keur') which are based on norms set in the provincial Water Regulation (Rijkswaterstaat, 2011). The twelve provinces, shown in Figure 2-1, are responsible for groundwater extraction for public drinking water, underground energy storage, and large industrial extractions. They make the aforementioned regional Water Regulation, which is based on national policy goals, and they supervise the RWAs. The municipalities manage urban stormwater and groundwater but do not have a big influence on agricultural water use. Figure 2-1 also shows the delimitations of the RWAs. This study focused on the province of Limburg, which contains the two RWAs Peel en Maasvallei (north) and Roer en Overmaas (south) within its borders. These RWAs are highlighted in Figure 2-2.

Not all RWAs have borders that match the provincial borders. There are agreements and rules governing the supervision of an RWA that spans more than one province. The main rule is that each province supervises the tasks on their own provincial territory, in a way that is synchronized with the other provinces. Some activities, such as devising a water management plan, cover multiple provinces. In those situations provinces use the mutual agreement that the province in which the

[1] Dutch farmers already built dikes and other water control structures as early as the eleventh century. As these structures became more complex, councils were formed by people with a common interest in water level control (mainly for drainage of agricultural land). The first democratic RWAs came into being around the 13th century. There used to be thousands of these RWAs in the Netherlands (Kuks, 2002).

largest part of the RWA is located acts as the coordinator (Personal Communication, Helpdesk Water, August 2013).

The European level also influences water management in the Netherlands, although so far the implementation in the Netherlands of the main European water policy, i.e. the Water Framework Directive (WFD), has been focused more on water quality than on water quantity aspects. It does, however, require implementation of pricing policies to promote efficient, metered water use and cost-recovery of water services, including environmental and resource costs. However, this is not happening in all member states of the European Union.[2]

This lack of action has led to a 'Communication on Water Scarcity and Droughts' with recommendations for policy instruments related to efficient water allocation and water efficient practices (European Commission, 2007). However, limited progress has been made in implementing these instruments. The European Commission (EC) proposes to make a water pricing policy an ex-ante condition to obtain financing under the Rural Development and Cohesion funds in the new Common Agricultural Policy. Another idea is to provide Rural Development funding to improve irrigation efficiency. Last year the EC also published a Blueprint to protect European Waters that focuses on increasing water efficiency (European Commission, 2012) as well as a report on the water saving potential in agriculture in Europe. It is to be expected that the European level will continue to influence agricultural water use.

[2] As for the Netherlands, the 2009 National Water Plan states that the search for new freshwater management strategies in the Netherlands will include cost recovery of freshwater facilitation and water pricing (Ministerie van Infrastructuur en Milieu, 2009).

2.2.2 Water Management Laws and Authorities in Florida

This section describes water laws and authorities in Florida.

2.2.2.1 Water laws and property rights

In the United States there are two main types of water use rights regimes. In many western states variations of the system of ‘prior appropriation’ are used, whereas in the eastern states including Florida the ‘riparian rights’-based systems are more common (Christaldi, 1996). In essence, prior appropriation means that the first actor to withdraw water from a water source has priority over later users. Land ownership by itself does not automatically guarantee water use rights. To use water, one must apply for a water right and prove that the water will be used ‘beneficially.’ Priority of use is determined by the date of application for the water use right. The right can be lost if it is not fully used, which provides a disincentive for water conservation. The riparian rights doctrine, by contrast, links water rights to property ownership. It gives landowners the right to withdraw and use water from water bodies adjoining their lands. This doctrine formed the basis for Florida’s current water regime.

Traditionally, riparian rights only applied to surface water and underground streams. Percolating waters could be extracted without limit, despite any negative effects such extractions might have on other users (Christaldi, 1996).[3]

Until 1957 water regulation in Florida was very fragmented, with many types of single-purpose districts such as flood and irrigation districts. The 1957 Florida Water Resources Act established an administrative agency for managing the development

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[3] According to Black Law’s Dictionary, percolating waters are waters which pass through the subsurface soil without a defined channel, and do not form part of the body or flow, surface or subterranean, of any water-course. This can be rainwater infiltrating through the soil or waters seeping through the banks or bed of a stream, and which have so far left the bed and the other waters as to have lost their character as a part of the flow of that stream.

of Florida's water resources. However, when it did not seem to reach its goals, water law experts at the University of Florida drafted a Model Water Code for Florida. This Code formed the basis of the 1972 Water Resources Act (Florida Statutes, 2013). The 1972 Act states that water should not be treated as private (riparian) property, which it had been until then, but as a public resource benefiting the entire state. It was to be managed on a state and regional basis, by allocating water so as to meet all reasonable beneficial uses (Swihart, 2011).

This meant that Florida’s water regime was changed to a system of ‘modified riparianism’ which allows riparian landowners to use water as long as the use does not unreasonably interfere with another riparian landowner's use (which also solved the issue of unlimited use of percolating water). The water use also has to be “reasonably related to the natural use of the landowner’s overlying land”. Florida’s current water law system also incorporates features such as permitting, establishing minimum flow levels, and watershed management, making it a system of ‘regulated riparianism’ (Swihart, 2011; Carriker and Borisova, 2009).

2.2.2.2 Water authorities

The 1972 Act established five Water Management Districts based on hydrologic boundaries. These WMDs, shown in Figure 2-3, are similar to the Dutch RWAs. They are responsible for day-to-day water management and have limited policymaking authority. A constitutional amendment passed in 1976 (after a referendum) gave the districts limited ability to levy ad valorem property taxes, i.e. within certain millage limits, specified per WMD (Carriker and Borisova, 2009).

Since 1997 WMDs also have had to assess the availability of water supplies for the next 20 years and prepare regional water supply plans. Furthermore, WMDs are required to implement regulatory programs for consumptive water use. They can have additional basin boards that report to the main governing board of the district (Swihart, 2011).

The 1972 Act appointed the Florida Department of Environmental Protection as the responsible body for the state-level water administration responsibilities. These responsibilities include supervising the WMDs and designing a state water use plan.[4] This plan has to focus on items such as minimum water levels and maximum water use. However, not much of this planning has occurred, which means water planning in Florida is still very fragmented (*Ibid*).

In both Florida and the Netherlands, the water rights regime has a history of change. In both regions water is seen as belonging to 'society' to be managed by the government. It is important to understand how this works out during permit applications and drought regulations, which is the topic of section 2.3.

2.3 Agricultural Water Use Permits and Drought Regulations

This section gives an overview of the regulation of agricultural water extractions in the Netherlands and Florida. It first describes the conditions for using water for irrigation, followed by the regulations under drought. It also describes the costs that are incurred for water extractions, and describes if there are monitoring requirements.

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[4] The supervision tasks include reviewing the priority lists for minimum flow levels; checking consistency with FDEP water resource rules; reviewing water resource development programs; assisting WMDs in developing regional water supply plans; preparing and distributing annual reports on the status of regional water supply planning; coordinating the state's response to drought; coordinating the Conserve Florida Water program; coordinating state-wide policy development on rules for water use permitting with the WMDs; and coordinating the Environmental Resource Permitting program (Swihart, 2011).

2.3.1 Agricultural Water Use Permits and Drought Regulations in the Netherlands

An estimated 65 to 85 percent of water used in agricultural production in the Netherlands is obtained through groundwater extraction (Hoogeveen, Bommel and Cotteleer, 2003). As was shown in Figure 1-3, most irrigation in the Netherlands takes place in the provinces of North-Brabant and Limburg, with their drought-sensitive, predominantly sandy soils.

2.3.1.1 Conditions for water extraction

In Limburg, some types of agricultural water use require a notification or permit from the RWA. This depends on whether the grower intends to use ground- or surface water for irrigation and whether or not this water is going to be taken from a priority area (a so-called buffer zone around desiccated natural areas).

As for agricultural groundwater extractions, both RWAs in Limburg have a notification requirement when the pumping capacity exceeds 10 m^3 per hour. Growers do not have to pay any fee for the notification. The notification mainly serves the purpose of monitoring the amount of groundwater that could potentially be extracted. Before 2008, groundwater extractions exceeding 60 m^3 per hour and any groundwater extraction within a buffer zone around a desiccated natural area required a permit. However, since 2008 the permit requirement has been abolished, and existing permits have been changed into notifications. The system was replaced by a stand-still policy, which was initiated by the provincial level and laid down in the Treaty of Venlo in 2007 between the province and the two RWAs. This policy aims to prevent further desiccation of natural areas and guarantee sufficient public water supply by not allowing any new wells for agricultural use. The policy is currently under revision, because it was seen as inflexible, and limiting farmers in their daily operations. The new policy is likely to become focused on preventing an increase in water extractions at the regional level instead of at the farm level. This means that growers will be allowed to extract water from every permitted or registered well outside the buffer zones (unless they already had a permit within the buffer zone)(Personal Communication, Waterschap Peel en Maasvallei, August 2013).

In Limburg, between 2000 and 2006, groundwater extractions of less than 60 m^3 per hour but more than 10 m^3 required use of ‘Customized Irrigation’ (in Dutch: Beregenen op Maat). This entailed mapping the soils on the operation and using either a software system or tables combined with a rain gauge to determine the optimal time and amount of irrigation. Customized irrigation also required growers to use pipes or tubes to monitor the groundwater level before irrigating, and they had to submit data on their irrigation behavior. Many growers still use this type of irrigation planning (60 percent of the growers in our sample), but there are no longer irrigation system or planning requirements.

In Limburg there used to be a maximum pump capacity for irrigation. However, recently, growers have been allowed to use pumps with a larger capacity because the enforcement of the restriction would require a lot of monitoring. Moreover, farmers indicated that suppliers were not always able to supply the smaller capacity pumps anymore (Personal communication, Waterschap Peel en Maasvallei, August 2013).

Surface water extractions (from all but national government waters) in Limburg have to be reported if they are between 5 m^3 and 10 m^3 per hour, and require a permit when the flow exceeds 10 m^3 per hour, if it is extracted from a primary water body or if it affects a primary water body. These permits are valid indefinitely. In some areas in Limburg, surface water extraction for irrigation is not allowed. For extractions from national government waters with a capacity exceeding 100 m^3 per hour the grower needs to either notify the government of this or get a permit, depending on whether the stream speed is lower or higher than 0.3 meters per second respectively. Moreover, some RWAs do not allow any summer daytime irrigation. Growers do not have to report how much surface water they use, in contrast to groundwater extractions exceeding 10 m^3.

2.3.1.2 Special regulations during drought conditions

During a drought, RWAs can use the regional 'Verdringingsreeks,' a list that prioritizes water distribution in a water consumption hierarchy. However, when there is drought and there is competition for water it is very difficult to reallocate it. RWAs have the authority to install an irrigation ban, although this normally only applies to irrigation with surface water. Compliance is checked by airplane monitoring. Such bans have been criticized for being inefficient because they are not crop-specific, even though marginal values of water use vary among crops (Hellegers and Ierland, 2003). In Limburg high-value crop production including vegetable cultivation is exempted from the ban. However, these bans might be able to increase the shadow price of a unit of water, thus providing an incentive for adoption of more efficient irrigation techniques or switching to crops with a lower water requirement.

2.3.1.3 Water charges

Most RWAs charge a one-time administrative fee for a water extraction permit application. They do not charge volumetric water charges and there are no limits on the quantity of water extracted. RWAs pay for the expenses incurred with their water-related responsibilities from the revenues of the Water System Fee, a charge per hectare that depends on the location (the RWAs have different fees), the type of land use, and the size of the farm's land surface.

In Peel en Maasvallei the fee for agricultural land is €33.45 per hectare; in Roer en Overmaas it is €42.44. This charge covers the costs of dike construction and maintenance, controlling the water level in the rivers, canals and ditches, and for keeping the waterways navigable.

Additionally, growers have to pay a pollution fee if they discharge polluted water. This is normally not the case for field vegetable production, but it is for greenhouse production. RWAs also charge households a water purification levy, but this does not apply to agriculture. Some RWAs charge farmers with a road levy, but the RWAs in Limburg do not. There are large differences in water-related costs for irrigating farmers between provinces, mainly because of differences in the water system fee between RWAs (Hoogeveen, Bommel and Cotteleer, 2003).

There is a provincial volumetric groundwater fee, but agriculture is exempted from paying this fee (Provincie Limburg, 2012). The main reason for this exemption is that there is a large number of relatively small extractions (average 10,000 m^3 per year, which would be equal to €145 of revenue for the average farmer). The province therefore thought it would be more effective to stimulate efficient water use by encouraging use of customized irrigation and weirs. Farmers in Limburg (except for those who use tap water) only pay volumetric costs for the energy it costs to move the water from the source to the field (i.e. about € 0.04 per m^3) (Hellegers and Ierland, 2003).

This overall water pricing system implies that externalities of agricultural groundwater extraction are not internalized in the water price. This likely leads to a situation where farmers maximize individual instead of social objectives. A low water price does not provide incentives for the adoption of drought adaptation measures.

According to Sterk Consulting, agriculture paid €130 million for the regional water system through the Water System Fee in 2012, as well as €0.5 million worth of groundwater system fees (Sterk Consulting, 2013).

2.3.1.4 Agricultural water use monitoring

Irrigators are required to 'measure' their groundwater extractions four times per year by taking the pumping capacity and multiplying it with the number of hours irrigated. This is not checked; the RWAs trust the farmers to be honest about this. If irrigators do not follow the rules of reporting their water extractions, then two reminders are sent. If the grower still does not report extractions, then a Special Investigation Officer can fine the irrigator. For RWA Peel en Maasvallei this happens approximately 30 times per year, out of 1,862 growers who are required to report extractions (Personal communication, Waterschap Peel en Maasvallei, July 2013).

2.3.2 Agricultural Water Use Permits and Drought Regulations in Florida

Section 2.2.2 showed that under the Florida Statutes (F.S.) water use permitting is a task of the WMDs.[5] Farmers must hold a Consumptive Use Permit (CUP) for ground- and surface water extractions exceeding the threshold determined by the WMD.[6] Growers who use water from a private, shallow well are exempted from the permit requirement (Olexa and Broome, 2011).

Farmers also need to apply for an Environmental Resource Permit (ERP) for activities that impact wetlands, adversely affect surface waters, or cause floodplain encroachment. Some agricultural activities can be exempted from ERPs. Growers also need a permit to drill a new well, although there are exemptions for growers who only use one small diameter (maximum two inches) well or surface withdrawal pipe

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[5] These are statutory laws (enactments of legislative authority) that follow the Florida Constitution.

[6] These and more information can be found at http://flwaterpermits.com/pportal/

on their own or leased property, which is intended for use only for farming purposes on the person's farm. Additionally, the water to be produced should be intended for use only by the grower, and the grower must comply with all local and state rules and regulations relating to the construction of water wells (Migliaccio *et al.*, 2012).

An application for a CUP includes the following information: quantity and source of the water; intended use; property and source location and acreage, and water conservation techniques that will be utilized.

For example, in the Southwest Florida WMD there are three types of CUPs, based primarily on the amount of water needed for a year: a so-called individual CUP for 500,000 gallons per day (gpd) or more; a general CUP for extractions between 100,000 gpd and 500,000 gpd; and a small general CUP for less than 100,000 gpd. The permit normally specifies the annual average gdp, as well as the gpd needed for the peak month, and the maximum amount of gpd used for crop protection from freeze events.

2.3.2.1 Conditions for getting a permit

There are three conditions for getting a CUP. Applicants have to demonstrate that the intended use is a reasonable-beneficial use,[7] and that it is consistent with the public interest.[8] They also have to show that their water use does not interfere with any existing permitted water uses. The permits are valid for up to 20 years. If the applicant leases the land adjacent to the water source, then the permit is only valid for the duration of the lease.

[7] i.e. a water use in such quantity as is necessary for economic and efficient utilization for a purpose and in a manner which is both reasonable and consistent with the public interest.

[8] This is determined on a case-by-case basis, and often involves consideration of water conservation and reuse, total amount of water allocated, and lack of saltwater intrusion, among other factors.

2.3.2.2 Special regulations during drought conditions

Under water shortage conditions the ‘local sources first’ policy requires water users to first try to obtain water in their own geographic area before proposing to get water from other counties or WMDs. Generally speaking, the available supply is equitably distributed. WMDs are allowed to impose reservations on water use to prevent harm to water bodies, for example for wildlife or public health. A 2010 law enacted by the legislature states that reservations and minimum flow levels have to be ratified by the legislature before going into effect. Under ‘emergency’ conditions more severe restrictions can be imposed, such as apportioning, rotating, limiting, or prohibiting the use of water resources for the district. Agricultural irrigation restrictions occurred for example in the 2006-2009 drought (Swihart, 2011).

2.3.2.3 Water charges

As in the Netherlands, farmers in Florida pay a property levy to the WMDs. In 1976 there was a referendum on the millage rate that the WMDs can charge. The rate was capped at $1 per $1,000 of assessed value in all WMDs except the Northwest Florida WMD. In the latter WMD the millage rate was capped at $0.05 per $1,000, one twentieth of the other WMDs. However, the other districts do not always charge this rate. For example, in the South Florida WMD the assessed millage in 2011 was 0.624 mills, i.e. 62.4 cents per $1,000 of assessed value. However, a volumetric water use fee would be more equitable than a property levy and would probably also reduce water demand and stimulate efficient water use (Swihart, 2011).

Additionally, fees are levied to offset the costs of processing and reviewing permit applications. These fees vary according to the type of permit and the size of the proposed project.

2.3.2.4 Agricultural water use monitoring

FDEP is currently leading an effort called CUPcon to improve consistency in water use permitting among Florida's WMDs. Monitoring rules for agricultural water use used to differ, but this process is currently being streamlined (FDEP, 2013c).[9] Water use data for all WMDs are tabulated at five year intervals by a cooperative agreement between FDEP and the U.S. Geological Survey (USGS). Two WMDs publish annual water use reports with water use information.

2.4 Drought Adaptation Support Programs

This section describes the support programs for drought adaptation in Florida and Limburg.

2.4.1 Drought Adaptation Support Programs in the Netherlands

Since the start of the Delta Program a lot of effort has been put into developing drought adaptation strategies for the Netherlands. In 2009 the Dutch provinces and national government reached an agreement on the efforts they will put into climate change adaptation. At the end of the same year the province of Limburg came up with the Action Program for Climate Adaptation. The program states that funding for climate change adaptation projects can be obtained through the budget for the provincial multi-year program for rural areas. It can also be obtained from the Knowledge for Climate fund. However, it does not specifically mention support for farm level drought adaptation.

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[9] In St. Johns River WMD permit holders must submit records of monthly pumpage data four times per year, calibration reports for water use accounting devices every five years, and compliance reports every ten years. In South Florida WMD permittees must also submit pumpage and monitoring data and other compliance reports such as calibrations and ten-year compliance. In Southwest Florida WMD Permittees who have 100,000 gpd or more annual average quantities have to submit an Irrigation Water Use Form at the end of each growing season. The District then calculates the Allocation Rate used for compliance with irrigation rules as well as 'irrigation credits' earned or used. According to their website, in the Suwannee River WMD monitoring and reporting activities 'may be required'. The North West Florida WMD does not give any information about monitoring of water use, but their website indicates they are cooperating in the CUPcon project.

Since 2009 several research programs have been created that focus on agriculture and freshwater availability, and a Delta Plan for the high sandy soils has been designed. The current phase of the Delta Plan focuses on creating a list with a small number of promising drought adaptation strategies. In 2014 this will lead to a strategy to increase freshwater availability, focusing on retaining and saving water, and increasing self-sufficiency. This could lead to cost-share programs for farmers.

The RWAs also have their own drought adaptation projects. Some of these projects focus on water saving through precision agriculture and use of satellite data to provide weather forecasts and inform irrigation decisions.

Other projects deal with desiccation on agricultural and nature lands through a 'Desired Ground- and Surface Water Regime' (in Dutch: GGOR). This regime represents the highest or best attainable quality, quantity, flow, depth, flow speed, morphology etc. of groundwater and surface water, as based on consensus between stakeholders. The regime had to be defined by the RWAs by 2005. It is based on the actual water regime and the optimal regime, and it includes a cost benefit analysis and considers the interests involved. The desired regime or water levels can be attained by placing weirs to retain rainwater and by using a special type of agricultural drainage where the farmer can control the groundwater level, which is described in the next chapter. The RWAs hope that these projects will solve the problems of areas being either too wet or too dry. For growers the goal attainment can be measured as the crop yield under the regime divided by the yield under the optimal regime. This regime also had to be defined at the watershed level under the main European water directive (Provincie Limburg, 2006).

In 2000 a project was started in Limburg (called 'Optimal Water management in Agriculture') to reduce agricultural groundwater use and stimulate on farm water conservation by farmers in areas surrounding nature areas. The program was intended to increase water use efficiency in irrigation. Buffer zones were appointed around the nature areas, and permit requirements were set for groundwater extractions in these zones. The agriculture and horticulture organization in Limburg has also helped farmers deal with drought by setting up pilot studies and subsidy-programs related to 'irrigation signals' and 'irrigation with precision techniques'.

2.4.2 Drought Adaptation Support Programs in Florida

In Florida there are drought adaptation support programs at the WMD, state, and national level.

2.4.2.1 WMD level

Most WMDs have agricultural demand management programs designed to increase the water use efficiency of agricultural operations. We describe the main programs for each WMD.

In the Southwest Florida WMD in 2006 the Southern Water Use Caution Area Recovery Strategy was published. To reach the goals of the strategy the District has developed the West-Central Florida Water Restoration Action Plan, which consists of several projects to develop alternative water sources, store water, and increase water use efficiency. The projects include encouraging farms to use excess surface water in the Flatford Swamp to replace groundwater used to irrigate row crops. It also includes encouraging tailwater reuse, and funds technology and best management practices (BMPs) research aimed at methods and technologies that can enhance water use efficiency.

Moreover, the so-called Facilitating Agricultural Resource Management Systems (FARMS) program is an agricultural BMP cost-share program developed by the District and the Florida Department of Agriculture and Consumer Services (FDACS) that hopefully will provide resource benefits including reduced upper Floridian aquifer withdrawals; and/or the conservation, restoration, or augmentation of the area's water resources. This is also part of the Southwest Florida WMD Regional Water Supply Plan. In the Southwest Florida WMD it is also possible to earn Water Conservation Credits when a grower uses less water than what is permitted, which can be used during drought periods.[10]

The Suwannee River WMD also has a district-wide program to support irrigation retrofits, new water saving technologies, and alternative water supplies. In the South Florida WMD the Water Savings Incentive Program (WaterSIP) provides cost-share funding of up to 50 percent or $50,000 (whichever is less) for water conservation efforts, such as soil moisture and rain sensor technology for irrigation systems. There is also a special program for growers in the Tri-County-Agricultural Area (TCAA; Putnam, Flagler and St. John counties) in the St. Johns River WMD, which provides support for drip irrigation and tailwater recovery. As stated earlier, the Northwest Florida WMD charges a lower property levy than the other WMDs, which might explain why they do not have a district-wide cost-share program to promote water conservation. They do support the State level Mobile Irrigation Laboratory (MIL) program, discussed below.

[10] The credit system allows growers to "carry forward" any unused permitted irrigation quantities, which may then be used as needed in subsequent years at the site for which they were earned or assigned. Additional credits may be earned by the permittee if less than the amount permitted is applied as reported in the reports required to be submitted to the District, based on metering. There is no limit to the credit amount which can be accumulated during the term of the permit (Southwest Florida WMD, 2013.Upon permit renewal, both assigned and earned credits which are unused can be carried forward for use during the term of the renewed permit (Southwest Florida WMD, 2011).

2.4.2.2 State level programs

At the state level, the Water Protection and Sustainability Cost-Share Program provides funding for development of alternative water sources, such as reclaimed water and brackish groundwater. In addition, all WMDs have an agreement with the USDA Natural Resources Conservation Service (NRCS) for an Agricultural Irrigation Efficiency Evaluation Project using a MIL. There are eleven MILs that provide free-of-charge help in analyzing irrigation systems and improving water use.

2.4.2.3 National level programs

At the national level, the Environmental Quality Incentive Program (EQIP) provides assistance for implementation of Water Conservation Measures (WCMs) through the Agricultural Water Enhancement Program (AWEP). As mentioned in chapter one Florida has a large number of these water-related EQIP contracts, which provide financial and technical assistance for implementation of WCMs. Most of the subsidies have gone to providing technologies that can reduce water application rates (low-pressure sprinklers or drip irrigation systems) or improvements that reduce water losses.

This section shows that there are more support programs for drought adaptation through increasing water use efficiency and water supply augmentation in Florida than in Limburg. It is therefore interesting for the Netherlands to learn about if and how growers in Florida use the cost-share programs, and how growers have chosen to adapt to drought.

Figure 2-1. Provinces of the Netherlands. Source: Author, using data from Aalst (2013).

Figure 2-2. Regional Water Authorities of the Netherlands. Source: Author, using data from Unie van Waterschappen (2013).

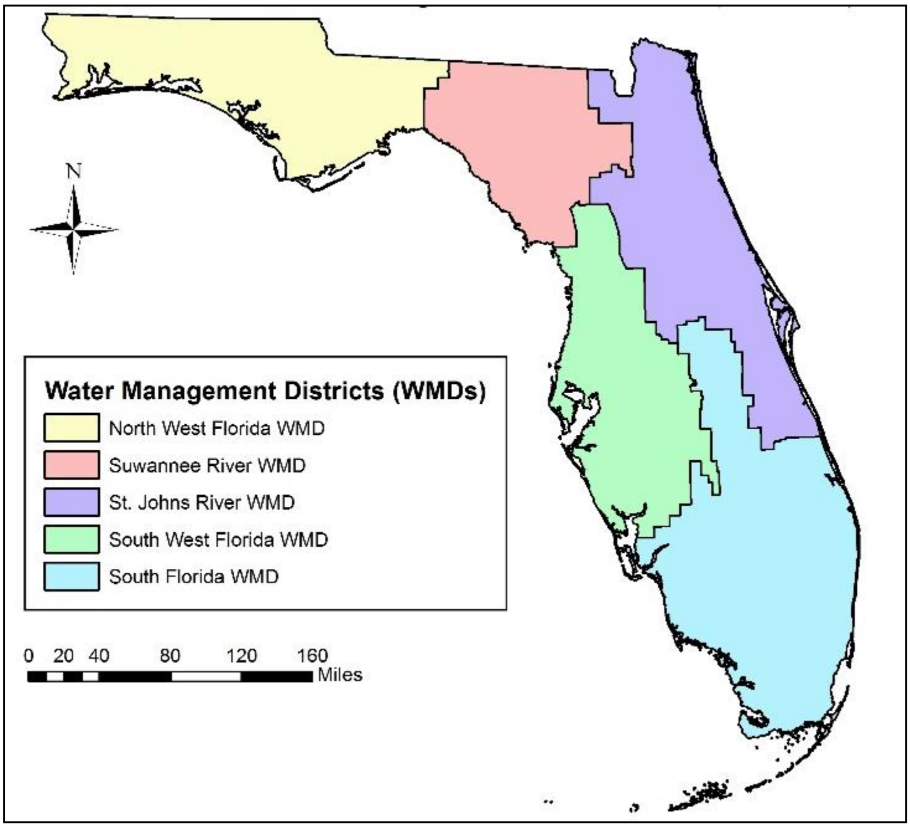

Figure 2-3. Florida's Water Management Districts. Source: Author, using data from FDEP (2005).

CHAPTER 3
DROUGHT ADAPTATION MEASURES

3.1 Categories of Measures

This chapter describes the farm-level measures that field vegetable growers in Florida and the Netherlands can take to adapt to drought. The focus is on long-term changes in technology and management practices rather than short-term adjustments that aim to keep the agricultural system on a status quo. The measures are grouped into two categories.

The first category (described in section 3.2) contains measures that increase the water supply at the farm-level. This can be achieved by using unconventional water sources such as reclaimed wastewater, desalinated water, or collected rainwater. Alternatively, it can be achieved by using existing water sources in different ways through tailwater recovery, agricultural drainage, or supplemental irrigation.

The second category (described in section 3.3) consists of WCM, i.e. measures that reduce on-farm water 'losses' during all the steps of moving water from the source to the crop. Water losses can be minimized with measures that increase the storage-, conveyance- or application efficiency of an irrigation system. Some measures minimize these losses by altering irrigation decisions and some through technological changes in the irrigation system. This section also gives an explanation of the rebound effect, which was not included in our model, but which was included in our survey (and for which we will describe the outcome for our sample in chapter six).

This chapter describes the measures' advantages and disadvantages, and when available, their costs.

3.2 Assessment of Supply Augmenting Measures

There are several ways to increase the on-farm water supply. This section describes six of them. The additional water can come from using reclaimed wastewater (3.2.1), from storing or infiltrating rain- and stormwater (3.2.2),[1] from reusing tailwater (3.2.3), desalinating brackish- or seawater (3.2.4), using agricultural drainage with weirs (3.2.5) or using supplemental irrigation (3.2.6).

All of these measures have some advantages in common, i.e. they can provide farmers with a reliable additional water source and reduce the amount of water extracted from the environment.

3.2.1 Reclaimed Wastewater Use

The practice of using reclaimed water reuses domestic wastewater after it has been treated and disinfected to a certain degree (in Florida at least with secondary treatment).[2] Wastewater reuse in irrigated agriculture mainly occurs in arid regions. In Cyprus 11 percent of total agricultural water demand is satisfied with recycled wastewater. In Spain 22 percent of collected wastewater is reused in agriculture (Cisneros, 2008).

Florida is among the leading U.S. states that reuse treated wastewater (Ibid). According to FDEP's 2012 water reuse inventory there are 486 domestic wastewater treatment facilities in Florida that treat 1,472 million gpd of wastewater (FDEP, 2013b). In 2012 over 14,056 acres of edible crops on 76 farms were reported to be irrigated with reclaimed water, all of them with micro-irrigation (Ibid.). Around 81 percent of this farmland was dedicated to the production of citrus, but some

[1] Stormwater is the precipitation that runs off of buildings, down streets, across parking lots, etc.

[2] Secondary treated effluents means that larger particles have been taken out and the water has been biologically treated. Often this means that the effluent has been screened, coagulated, and sand filtered, Ph-adjusted with sulphuric acid and cartridge filtered, and treated with air and a biological floc to reduce the organic content (activated sludge).

vegetable producers also used reclaimed water. Moreover, the Water Conserv II project west of Orlando is one of the world's largest reuse projects using reclaimed water for agricultural irrigation and groundwater recharge.

In the Netherlands, 99 percent of all municipal wastewater is treated and discharged into surface water, and the sludge is burned. It is not used directly for irrigated agriculture (Cisneros, 2008). A Dutch expert indicated that using reclaimed water for irrigation poses health risks, unless the reclaimed water is applied through subsurface irrigation, because then the soil and the root system will filter the clean water out of the wastewater (J. Elshof, personal communication, July 2013). However, nutrient-poor sandy soils with low groundwater levels could benefit from irrigation with reclaimed water.

3.2.1.1 Advantages and disadvantages

A specific advantage of reclaimed water use is that fertilizer costs can be reduced because nutrients in reclaimed water can be used by crops (Morgan, Wheaton, Parsons and Castle, 2008). In Florida reclaimed water is often of higher quality than surface water because of higher treatment standards (York, Parsons and Walker-Coleman, 2011).

However, social attitudes towards the use of crops that have been irrigated with recycled water and the resulting impact on market value of crops are an important consideration (Toze, 2006). Also, in order to be able to use reclaimed effluent water, one has to be close to a municipal or urban water treatment facility.

In some areas, higher treatment standards are needed because the quality of reclaimed water can raise concerns related to the contamination of the soil, surface, and groundwater, reduced crop quality, and public health. While the nutrients contained in reclaimed water can be a possible advantage, when nutrient concentrations are too high, nutrients become a disadvantage. Other potential problems include the presence of heavy metals or contaminants such as pathogens and pharmaceuticals. As a consequence, reclaimed water use in irrigation is often regulated according to standards. For example, the Florida Administrative Code (F.A.C.) specifies waste treatment and disinfection standards and prohibits the use of reclaimed water for irrigation where direct contact will occur with edible crops that will not be peeled, skinned, cooked, or thermally processed before human consumption.

Besides regulations, many of these water quality issues can also be overcome with farm-level water treatment, although this can be costly. For example, salt can only effectively be removed with reverse osmosis membrane filtration. However, there are conditions under which this treatment can be circumvented without adverse consequences for the crops. For example, if the soil is porous and low in clay it is often sufficient to check that the water moves through the soil (Toze, 2006). Other options are to mix the treated wastewater with water that has a lower salinity level, or occasionally irrigating fields with water with a low sodium concentration to flush the accumulated salts out of the soil (*Ibid*). Growers can use biological treatment to remove organic substances, and then use deep-sand filtration to remove heavy metals and disinfect the water with ozone or ultraviolet treatment (Cisneros, 2008).

A third option is to manage health risks through agronomic practices like crop selection, timing of irrigation (at night, or when the least number of people is present on the fields when irrigating), type of irrigation, and harvesting measures (such as crop drying before harvesting). In terms of the irrigation system, the lowest health risk is associated with subsurface or drip irrigation, although emitters can get clogged (*Ibid).*

3.2.1.2 Costs

The feasibility of wastewater reuse in irrigation depends on soil characteristics, the type of drainage system, crop type and -value, storage system, operation and management (O&M) conditions, water quality, and type of irrigation system (Cisneros, 2008).

A recent study on the Colorado River Basin stated costs for using reclaimed municipal water between US$1,500 and US$1,800 per acre-foot per year (afy). This is the amount of water needed to cover one acre to a depth of one foot. This would mean a cost of $1.22 – $1.46 per m^3 per year. The authors also state that it will take another 10 to 35 years until this is a viable option in their basin (USDOI, Bureau of Reclamation, 2012).

3.2.2 Rainwater Collection and Storage

Rainwater harvesting is promoted by the Florida agricultural BMP manual (FDACS, 2005). The collected water can be stored underground (in creek ridges or aquifers) or in basins or tanks.

3.2.2.1 Rainwater storage in reservoirs or tanks

When using a reservoir to store rainwater it is helpful to have an impenetrable bottom or canvas lining to reduce percolation losses. Rainwater can also be collected from the roof of the farm building, although in field vegetable production there are generally less roofed areas to be used than in greenhouse production. Still, growers can collect water from the rooftops of their storage areas and other roofed areas. Growers can also take water from a ditch after a heavy rain event. Depending on whether or not the reservoir is covered, evaporation will need to be deducted from the water yield.

3.2.2.1.1 Advantages and disadvantages. The quality of collected rainwater is generally rather high. The basin could be used for other functions as well, such as providing green services. One disadvantage, especially when land values are high, is that the reservoir will take up space: one m^2 per cubic meter of water for a reservoir with a water depth of one meter (Bakel and Poelman, 2009). Another possible disadvantage is that capturing rainwater before it becomes run-off and contributes to streams or recharging aquifers might harm the ability of other water users to use this water.

3.2.2.1.2 Costs. The costs of building a reservoir include the opportunity costs of the land on which the reservoir is built, the costs of digging or building the reservoir, canvas to line it, and material to cover the sloping sides. There are also costs related to using the reservoir such as the cost for a pump and for fuel.

The opportunity costs of the land for the Dutch study region Limburg are a maximum of €634 per hectare (ha) or per 10,000 m^3 per year for a reservoir with a water depth of one meter (Ministerie van Economische Zaken, Landbouw en Innovatie, 2012). For a 10,000 m^3 basin, Royal Haskoning gives a price of €30,000 to build it, €4,000 for the pipes, and €2,000 for the pump (Blokhuis and Lodewijks, 2005). They calculated the costs per year using a lifespan of twenty years for the basin, 17.5 years for the pipes, and fifteen years for the pump. They also state energy costs of €1,500 per year and a land rental value for their study area. Taking these costs together and substituting Limburg's land rental value in the calculation leads to a cost of €0.40 per cubic meter of water.

In a different study Bakel and Poelman (2009) stated prices of €0.35 per cubic meter of water for building and maintaining a lined reservoir, and €0.15 for an unlined reservoir. This is the price considering that the reservoir will be fully used every year, which is unrealistic (Bakel and Poelman, 2009). The study assumed a larger reservoir (20,000 m^3) than the Royal Haskoning study which lowers the price per cubic meter of water. On the other hand, the study uses a higher land opportunity cost: €2,000 per hectare (for grassland) and thus €0.10 per cubic meter of water. With our land rental value this would be a cost of €0.03 per cubic meter. In terms of energy costs the authors state fixed costs of € 200 per ha per year and variable costs of €0.20 euro per m^3. Assuming a grower irrigates 100 mm per year the energy costs are € 0.40 per m^3. Substituting Limburg's land value this would mean a cost of €0.58 - €0.78 per cubic meter of water.

3.2.2.2 Underground rainwater storage

Aquifer Storage and Recovery (ASR) is a practice where water is injected into an aquifer (with one or more wells) and extracted when it is needed. The amount of water that can be recovered when extracted depends on the location; often the rate is between 50 and 100 percent.

3.2.2.2.1 Advantages and disadvantages. ASR is useful when the groundwater is of poor quality or when it is insufficiently replenished. It requires a suitable aquifer, ideally with impenetrable layers above and below the aquifer. There should also be minimal horizontal movement, and sufficient water available during a wet period. This can be increased by collecting water from rooftops, ditches, or temporary rainwater storage in basins. However, ASR can increase saltwater intrusion because of the increased water pressure. Moreover, it has to be done in accordance with laws governing soil and water quality (Tolk, 2012).

3.2.2.2.2 Costs. In the Netherlands ASR has installation costs between €50,000 and €150,000 (with a lifespan of 15 to 25 years), which includes the costs for installing the wells, the water basin, sensors, a central control unit, engineering, and geohydrologic advice (Nikkels, 2013). ASR also involves maintenance and operating costs between €10,000 and €30,000 per year, depending on the scale

(Tolk, 2012). This does not include the energy costs, which are an additional €2,000 to €3,000 per year. Is it not clear exactly what costs are covered under operation and maintenance. Then there are costs of €34,000 to €190,000 for the pipes, with a lifespan of 10 to 25 years, and the costs of the pump are stated as €2,000 with a lifespan of 10 to 20 years. If water is stored during the wet season and extracted during the dry season the total costs per cubic meter, including depreciation and interest costs, are between €0.30 and €1.38 per m^3 (Vink, Rambags, Gorski and Kooiman, 2010). The more water is injected and recovered, the lower the costs per cubic meter, for which the authors state a lower bound of €0.17 per cubic meter (Tolk, 2012).

3.2.3 Tailwater Recovery

Tailwater recovery is the practice of collecting and reusing irrigation water that runs off the fields. The recovery structure will often also retain rainwater and the subsurface lateral flow above a spodic horizon (a relatively impermeable layer of accumulated organic matter), when this is present. The difference between tailwater recovery and rainwater storage is that for tailwater recovery water is often collected in a pond at the low end of a field or water control structure or culvert, and moved by pipes and pumps.

Tailwater recovery can provide larger water savings for seepage or flood irrigation systems, than for more efficient irrigation systems. It is a measure that is promoted by the Florida BMP manual for vegetable and agronomic crops.

3.2.3.1 Advantages and disadvantages

Tailwater recovery can reduce nutrient run-off. However, the system requires cleaning, and the collected water has to be checked for sediment and nutrients. It is important to note that reusing return flows through tailwater recovery reduces field-level water losses but can reduce return flows to downstream users.

3.2.3.2 Costs

Carman (2005) states costs of US$150 - 225 per acre for construction costs. This includes $1.00 per cubic yard of earth work (excavation or earth fill) plus $5.00 per foot for a 10-inch pvc high-pressure pipeline installation. There are also costs for the pump and the energy source (Carman, 2005). The cost per m^3 depends on various factors such as the irrigation system and tailwater recovery structure used.

3.2.4 Desalination

Over the past decades, a lot of progress has been made in desalination technologies. For an overview of the different desalination technologies and their costs, see Beltrán and Koo-Oshima (2006). Worldwide, most desalinated water is used for domestic supply and with less than 10 percent of desalinated water used in agriculture because of the costs (*Ibid.*).

3.2.4.1 Advantages and disadvantages

To desalinate or use desalinated water a grower needs to have access to seawater, brackish groundwater, or a desalination plant. A specific advantage is that many desalination technologies also remove contaminants from the water. This is one of the reasons why hydroponic farmers in Florida are increasingly desalinating water for irrigation purposes. However, on-farm desalination is costly and can be difficult.

The membranes are sensitive and can get bacterially contaminated, the feedwater usually needs to be pre-treated to remove particles, and there is often a need for assistance to construct and operate the plant (Beltrán and Koo-Oshima, 2006). Moreover, brine must be carefully disposed of to prevent adverse environmental effects.

3.2.4.2 Costs

According to FDEP the costs of treating saline water at a desalination plant with a 10 mgd capacity range from \$3.20 per thousand gallons for brackish groundwater to \$5 per thousand gallons for seawater (FDEP, 2010). This means desalinated water is often expensive for agricultural producers to buy.

On-farm desalination requires significant investments in the installation of the plan, O&M costs, environmental costs, and other indirect costs (Beltrán and Koo-Oshima, 2006). Beltrán and Koo-Oshima quote investment costs of \$700 to \$900 and O&M costs of \$0.68 to \$0.92 per cubic meter. The authors conclude that desalination of water for agricultural irrigation is cost-ineffective, except for production of high-value crops such as flowers and field vegetables in arid coastal regions (*Ibid.*). In the future costs might go down further. Also, costs are lower for larger treatment plants. Therefore buying desalinated water from a large treatment plant is an easier option, albeit still a costly one.

3.2.5 Composed Water Level-Steered Agricultural Drainage

Water level-steered agricultural drainage (WLSAD) is a practice that is mainly being applied in the Netherlands, although it bears resemblance to some of Florida's seepage irrigation systems. It is a type of drainage where the groundwater level can be dynamically managed. It works through a system where all the drains discharge into a collection drain that is connected to a collection well where the water level can be controlled. This is shown in Figure 4-1. The left panel shows the situation without any drainage, and the panel on the right shows the situation with WLSAD. The top images show the water level during the wet period and the bottom images show water level during the dry period.

During the wet season the grower can increase the level to store more water. When it is time for the machinery to enter the land, it can be lowered again. During a dry period the level can be raised to ensure more moisture is available, and when there is a risk of water damage the level can relatively quickly be lowered again, especially on sandy soils. The water level can be set at either 50 cm below the ground surface for cultivated agricultural land, or at 30 cm below the ground surface for grassland. RWA Peel en Maas wants to have all land in North and Central Limburg managed by WLSAD by 2018.

3.2.5.1 Advantages and disadvantages

The groundwater level can be raised by an average 35 to 50 cm compared to conventional drainage (wpm.nl). An experiment in Limburg showed that with WLSAD fewer irrigation events were necessary (Alterra, 2010). Also, WLSAD requires less maintenance than regular drainage because the tubes are under water and the system flushes itself (*Ibid.*).

3.2.5.2 Costs

One RWA in Limburg states that the costs for a new WLSAD system are €450 per hectare for the collection drain and well. This does not include the costs of the regular drains. Converting an existing drainage system to a system of WLSAD costs €600 per hectare. A WLSAD company states that the costs of WLSAD are 2.5 times the price of conventional drainage, thus leading to a price range for WLSAD of €1,000 to €2,400 (Tolk, 2012). Alterra (2010) states a price of €2,400 for a new system or €1,250 when converting an existing drainage system. With a pipe lifetime ranging from ten to twenty years, and a WLSAD drain and well lifespan of fifteen to twenty years, the costs per hectare per year range from €30 to €160 (Tolk, 2012).

3.2.6 Supplemental Irrigation

Farmers normally use supplemental irrigation for several reasons: to improve the moisture supply to crops, for freeze protection, for fertigation, to prevent damage to watercourses, and in some cases to prevent soil subsidence (Bakel and Stuyt, 2011). Because this is an oft-used way of adapting to drought we describe the irrigation systems that are currently used in Florida and the Netherlands. We first describe the term irrigation efficiency.

3.2.6.1 Irrigation efficiency

There are more than 30 definitions of irrigation efficiency (Edkins, 2006). It can be defined at the crop, field, or regional level, for each irrigation system component (reservoir, conveyance, application), or for an entire irrigation system. In this study we focus on water use efficiency at the field or irrigation system level. In this context, efficiency refers to the volume of water used beneficially relative to the volume delivered by an irrigation system (Huffaker, 2008) or the increase in crop yield over non-irrigated yields, relative to the volume of water applied by the irrigation system (Smajstrla *et al.*, 2002). The water productivity of the irrigation system (WP_{IR}) can be defined as the ratio of biomass with economic value over the total amount of water received. WP_{IR} can be increased by reducing non-productive outflows of the field such as run-off, seepage and percolation, thus reducing the amount of water that needs to be diverted. The aim is generally to reduce these outflows on a level that does not threaten evapotranspirational requirements. This efficiency can be increased at several components of the irrigation system.

The first partial efficiency of an irrigation system is the conveyance efficiency. This refers to the percentage of the water that is taken from the source that actually reaches the field. This efficiency depends on the type of conveyance infrastructure and how it is maintained. For example, an open channel has higher losses due to evaporation than a pipe system. The second partial efficiency is the field application efficiency, which is the percentage of water delivered to the field that the crop uses. Here losses occur through evaporation, run-off, and deep percolation. The efficiency does not only depend on the system, but also on its management and maintenance, and on external factors. For example, losses can occur due to leaking pipes, strong winds, timing of the applications, and uneven terrain. Even though some conveyance systems generally have higher efficiencies, the actual irrigation efficiency can be lower for a particular application, for example due to lack of application uniformity (Edkins, 2006).

Based on our definition of irrigation efficiency, irrigation systems can be ordered from least efficient to most efficient in the following general categories:

1. Low volume or micro-irrigation: drip irrigation, microjet, microsprinkler
2. Sprinkler irrigation: traveling gun, overhead
3. Surface irrigation: ridge, flood, furrow, seepage

The more efficient the system, the more yield can be achieved with the same amount of water diverted or extracted from the source. Adoption of more efficient irrigation technology is therefore often seen as a highly effective drought adaptation measure at the farm level.

Micro-irrigation systems typically have high application efficiencies (90 to 95 percent) because they distribute water near the crop's root zone. Micro-irrigation, depending on the way it is used, generally uses less water than sprinkler systems, and it is possible to apply fertilizer with the irrigation. Moreover, water distribution is precise, foliar diseases are reduced, and it allows for electronic scheduling of irrigation on large areas with smaller pumps relative to sprinkler systems. However, there are differences between drip irrigation and micro-sprinkler irrigation. For drip irrigation there are hardly any losses due to wind drift and evaporation (Boman, 2002). Micro-sprinkler systems are less efficient than micro-drip systems, since they can have higher wind and evaporation losses on hot, dry, windy days, so good management is needed. Precise efficiencies depend on hydraulics of design of the system and on maintenance and management (*Ibid*.). In Florida micro-irrigation is widely used on high-value vegetables.

For drip irrigation, water with a higher salinity level can be used because the water does not touch the leaves. For crops that need annual plowing, the drip irrigation tubes have to be replaced annually. Drip irrigation at 30 cm below ground level (and below the plowing layer) can solve this problem. Drip irrigation can also increase crop yields, reduce nutrient applications, and nutrient runoff/leaching. The peak demand is also reduced, so more hectares can be irrigated with the same amount of water.

The costs of drip irrigation depend on the crop type (seasonal replacement required or not); the thickness of the pipe material, and the lifespan of the system. Assuming a three season lifespan of a drip irrigation system with a pipe material thickness of 0.37 mm, with a pump with a 10 to 20 year lifespan, building the system will cost €2,167 - €2,667 per hectare per year, and €50 – 200 for the pump. Operation costs include the costs of moving the pipes, €300 – 600 per hectare per year; running costs, €225 – 300 per hectare per year; and energy costs, €100 – 150 per hectare per year, yielding a total of €2,842 – 3,917 per hectare per year (Tolk, 2012).

Sprinkler systems are mainly used for row vegetable crops such as potato, sweet corn, and snap beans. Between 1.5 and 7.6 percent of irrigated water can be lost as a result of wind drift and evaporation alone (Smajstrla *et al.*, 2002). Simonne, Dukes and Haman (2007) state application efficiencies in Florida are between 60 and 80 percent. The exact efficiency depends on the hydraulic properties of the pipe network. Good sprinkler systems have less variable efficiencies than seepage or surface irrigation systems, which depend strongly on soil hydraulic characteristics. Perfectly uniform application is impossible to achieve because of friction losses, elevation changes, and other factors. Non-uniformity can occur with bad positioning, for example when the sprinklers overlap (Smajstrla *et al.*, 2002). Night irrigation is more efficient than daytime irrigation. As an added benefit to sprinkler systems, overhead irrigation is also commonly used to protect crops from freeze damage in Florida, creating a second use for the system. Heat is released as the applied water changes to ice.

There are several types of surface irrigation systems. The main types are flood, furrow and seepage irrigation. Water distribution from seepage irrigation systems occurs below the soil surface. Many growers in both Florida and the Netherlands use this irrigation system because of its relative ease of operation and low infrastructure cost. Wind and other climatic factors do not affect the uniformity of water application, although this depends on the soil topography and hydraulic properties (Boman, 2002). However, seepage irrigation has a very low application efficiency as a result of the large amount of water required to constantly maintain a shallow water table throughout the crop season. This may also cause nutrient leaching (Pandey *et al.*, 2007). Seepage irrigation in Florida only has application efficiency between 20 and 50 percent (Simonne et al., 2007).

Flood and furrow irrigation are also inefficient in terms of water use because of evaporative and percolation losses. Runoff reduces irrigation application efficiencies unless this water is collected in retention ponds and used for irrigation at a later time (Smajstrla *et al.*, 2002).

3.2.6.2 Current irrigation systems used in Florida

There is a wide range of irrigation systems in Florida, depending on crop type and agricultural conditions. As can be seen in Table 3-1, in 2005 1,783,053 acres or 46 percent of the total acreage used for production of vegetables, fruits, field crops, and ornamental plants and grasses in Florida was under irrigation. Of this land, 38 percent was irrigated with micro-irrigation. Sprinkler irrigation methods were used for 19 percent of the irrigated acreage, and the remaining 43 percent were irrigated with flood irrigation (Marella, 2008).

According to data of the Farm and Ranch Irrigation Survey, in 2008 2,211 field horticultural production farms in Florida used some form of irrigation. There were 1,493 commercial vegetable operations harvesting a total of 265,835 acres. Table 3-1 shows how many growers used each type of irrigation system.

The data also show that 83 field horticultural growers used recycled tailwater, and 44 purchased reclaimed water at $1 per thousand gallons. Moreover, 792 growers used irrigation to prevent freeze damage, 253 for preventing crop heat stress, and 63 growers used it to leach salts out of the soil. There are no large differences in use of irrigation by horticultural farms in terms of income categories. Growers in Florida mainly use groundwater to irrigate, and to a lesser extent, surface water. Reclaimed water and desalinated brackish groundwater are also increasingly used (USDA NASS, 2010).

3.2.6.3 Current irrigation systems used in the Netherlands

The annual agricultural survey in the Netherlands asked growers in 2010 about the irrigation systems they use, as well as the water source with which they irrigate. We show these data in table 3-1 as well. An analysis of these data showed that in Limburg, of the growers that are classified as mainly horticultural field vegetable producers, 36 percent use no supplemental irrigation. Of the remaining 64 percent, 62 percent use sprinklers or hoses, and 0.5 percent use flood irrigation. The percentages do not add up because 2 percent of the growers use more than one type of irrigation.

3.3 Assessment of Measures that Reduce Non-Productive Water Losses

This section describes several measures that can increase the storage, conveyance, and application efficiencies of irrigation. For any grower who uses a different type of irrigation than micro-irrigation, non-productive water losses can be reduced by switching to micro-irrigation. However, this is not appropriate for all crops. This section focuses on other measures that growers can use to reduce water losses, including soil leveling and mulching.

3.3.1 Land Leveling

Water losses in irrigation sometimes occur because the terrain is uneven. Growers will typically over-irrigate some part of the field if this is the case, because they want to make sure all the crops get at least sufficient moisture.

3.3.1.1 Advantages and disadvantages

Land leveling conserves water by creating a uniform slope gradient that leads to more uniform water application. It can also improve drainage and reduce erosion, and improve uniformity of crop growth and yield. However, it is a soil disturbance that changes the equilibrium of soil properties such as bulk density, water retention capacity and pH value (Öztekin, 2013).

3.3.1.2 Costs

The costs of land leveling depend on the soil type, the initial level of uniformity in the terrain, the machinery used and fuel costs. Initial costs per acre for land leveling can range from $50 to $400. Touch-up land leveling usually costs less than $25 per acre (Texas Water Development Board, 2005).

3.3.2. Mulching and Soil Structure Measures

Growers can apply measures that improve the soil structure in order to increase rainwater infiltration, improve the moisture retention capacity of the soil and reduce evaporation. Most of these measures increase the soil organic matter content. There are target values for organic matter content for different soil types (Vlaco, 2009; ZLTO, 2011). The grower can also change the crop rotation, stimulate 'soil life,' use mulching, or enlarge the root zone. To improve the organic matter content, growers can use compost, green manure (winter crop that is then tilled back into the soil in springtime), or no-tillage.

Another potential option for the future involves the use of artificial terra preta (fertile, black dirt that is found in rainforests) to improve the soil. This is still being developed (Tolk, 2012).

3.3.2.1 Advantages and disadvantages

A soil structure with a higher organic matter, better 'soil life,' a larger root zone, or covered by mulch better retains water. This can reduce desiccation, increase crop yields and reduce the need for supplemental irrigation. It can also reduce water runoff during heavy rain events. In a Belgian study by a compost producer (Vlaco, 2009) the authors stated that applying 15 tons of vegetable/fruit/garden-compost per hectare per year during nine years led to a one volume percent of extra moisture in the soil.[3] The same experiment with 45 tons led to 4 percent extra water. Applying 'humus acids' led to an increase of up to 9% soil moisture, depending on the amount of organic matter in the soil beforehand (Vlaco, 2009; Bal and Verhage, 2011).

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[3] Soil moisture content is often expressed in percent of volume. Thus, a moisture content of 100 mm/m corresponds to a moisture content of 10 volume percent (Brouwer, Goffeau and Heijbloem, 1985). For example, if a soil sample weighs 230 grams in a moisture box, and the mass of the moisture box is 78 g, and after drying at 105 degrees C to a constant mass, the soil and box weighed 204 g, and the soil sample filled a 1000 cc container as it was taken from the field, then the moisture percentage in the soil by volume is equal to (vol. of water / bulk vol. of soil) x 100. Vol. of water = mass of water / density of water = 26 g / 1 g per cc = 26 cc. Hence: Water (%) by volume =(26 cc / 1000 cc) x 100 = 2.6 % (Icrisat, 2013).

According to Vlaco (2009) one volume percent of soil moisture equals ten liters of water per cubic meter of soil, with a depth of 0.3 m of compost.

However, current manure regulations (mainly related to nitrogen and phosphorus levels) restrict the farmers in putting organic matter on the soil (Schoot and Haan, 2012). Often growers in the Netherlands prefer to apply manure to compost because they get compensated for this by farmers who have a manure surplus. Despite this compensation many growers use compost because of the positive effects on soil fertility (Jonkheer and Haan, 2010).

The effect of increasing the organic matter content of the soil depends on the initial amount of organic matter present in the soil, the type of crop grown, and the soil type. The effect is largest on soil where the initial organic matter content is low, where a crop is grown that allows for uncovered soil for part of the year, and on sandy soil. On sandy soils the effect can be up to 15 percent of the variation in soil moisture. On soils with a finer structure such as clay, the organic matter decreases the volume density, increases the sizes of pores, and can thus even reduce the soil moisture retention capacity (Bal and Verhage, 2011).

A study done for the Province of Flevoland stated that increasing the organic matter content of the soil would cost 10 labor hours per hectare per year and €100 in energy per hectare per year. The model used in the study predicted an increase in output of potatoes and onions of 4 percent, and sugar beet, wheat and other arable output by 1 percent (Wolf *et al*., 2011). Of course the yield effects for horticultural vegetables could be very different.

3.3.2.2 Costs

The prices of compost differ with respect to the source. Generally, domestic organic waste is less desirable than organic waste from parks and natural areas, because it contains less plastic, glass and salt remains than the latter. Vlaco (2009) uses a price level of €16.16 per ton of organic waste and €12.12 per ton of domestic organic waste in Belgium. In Jonkheer and Haan (2010) the highest quality domestic organic waste in the Netherlands is said to cost between €2.50 and €4.50 euro per ton, and green compost €8.00 per ton. The differences in prices may be due to the fact that they are costs for different countries; there may be differences in the amount of waste collected, and in the way the waste is processed between Belgium and the Netherlands. In the Vlaco experiment the researchers applied 15 tons of compost at €2.50 per ton during nine years, leading to a cost per hectare of €338. They also did an experiment where they applied 90 tons per hectare of compost costing €16.16 per ton, leading to a total cost per hectare of €13,090.

3.3.3 Increase Storage and Conveyance Efficiency

Storage and conveyance efficiency can be increased through reservoir and delivery canal lining and covering, and canal to pipe conversion. Also, improved canal control and construction of regulation reservoirs can reduce canal operational spills. Reducing evaporative losses from canals and reservoirs can reduce water use.

3.3.4 Change Irrigation Planning

Irrigation scheduling means applying water to crops at the ‘right’ time and in the ‘right’ amount. Scheduling often consists of grower judgment or a schedule of irrigation events based on previous seasons. Factors such as plant evaporation, soil characteristics, and root distribution are also important for irrigation scheduling (Locascio, 2005). Growers can use soil moisture sensing devices to inform their water application decisions. Besides using information on soil moisture, growers can also use weather systems, at the farm or based on regional weather information. This can be combined with computer-based plant growth simulation models. Another innovation is the use of variable-rate irrigation systems, which allow for different irrigation rates in different field sections.

3.3.4.1 Soil moisture sensors

Optimizing the soil moisture for crops can reduce drought damage, and increase yields and crop quality. Sensors are normally placed every 10 cm in the soil to measure soil moisture. Several types of sensor systems exist. They all measure some physical property that is correlated with soil moisture, such as electrical resistance.

3.3.4.1.1 Costs. There are large price differences between different types of sensor systems. Some sensors are portable, and have to be pushed into the soil or into an access tube in the soil. A single, standalone hand-push tensiometer without data storage can be bought for around $70, although for $100 to $500 the grower can purchase a more sophisticated sensor with faster readings.[4] Tensiometers are fairly easy to use but need to be serviced regularly. Other sensor systems are buried, and can be either directly connected to a fixed meter or have long wires above-ground that can be connected to a portable hand-held meter (which cost between $150 and $600). Portable sensors are suitable for growers who often check their fields and want to take measurements manually. It also does not involve burying cables on the farmland. However, it can be difficult to retrieve buried electrodes.

However, tensiometer measurements can be affected by influences of temperature and salinity, leading to inaccurate moisture readings (Ling, 2004). The grower can also attach an automated data logger, which allows the grower to download the data onto a computer. The grower can use this continuous data to identify trends. A more advanced data logger uses wireless communication to send

[4] A tensiometer is an airtight, water-filled tube with a porous ceramic tip on the end that is placed in the soil, with a vacuum gauge on the other end that protrudes above the ground, which displays the soil water tension.

the data to the computer automatically. Depending on their features, soil moisture data loggers cost between $60 and $500, not including sensors or cables (Morris, 2006).

For buried sensors, the number of sensors needed depends on the heterogeneity of the soil. A homogeneous soil generally requires one set per ten hectares; heterogeneous soil requires one set for half a hectare. Sensors last between ten and twenty years. In the Netherlands two companies state costs between €445 and €4,717 per hectare per year, including the costs for drip irrigation (WaterSense, 2013; Dacom, 2011). The Kennisakker website states initial costs for one sensor and software of €2500 and annual maintenance costs of €950 (Kennisakker, 2013). Since this price only includes one sensor, growers with non-uniform parcels do not have information about the conditions on another part of their operation. To deal with this problem, the company providing the sensors and software has added a new feature to their software that incorporates satellite images.

3.3.4.2 Weather station and automatic irrigation

The soil sensor systems described above can be expanded with other features to make up an entire weather station. Growers in the Netherlands can also register and use the service of a company that has weather station data. In the Netherlands the average distance to such a weather station is 7.5 km (Dacom, 2011). The station measures precipitation, and sometimes also wind, temperature, and moisture levels, including soil moisture levels for an on-farm weather station. When the grower has his or her own station, this information is automatically sent to the computer where software calculates the optimal irrigation moment. These technologies can reduce water applications and increase yields. Installation costs are between $50 and $100 with Aqua Conserve. The station costs $250, and then the controllers cost between

$135 and $240 depending on the number of stations. Weathermatic offers a complete package for $350.

Some soil moisture instruments can also automatically control irrigation. When the soil moisture reaches a trigger point as set by the user, then the sensor system switches on the irrigation. However, it may take some time to understand how the soil moisture data should be used to determine irrigation decisions (Shortt and Verhallen, 2011).

3.3.4 Alternative Freeze Protection

Freeze protection for crops can be given in ways that do not require additional water. In this study we focused on the use of wind machines, tunnels, and row covers.

3.3.4.1 Advantages and disadvantages

Wind machines are effective during periods when the ambient wind speed is less than five mph, because then the air close to the ground is much colder than the air at 50 to 100 feet aboveground. This temperature inversion does not occur when it is windy, because then there will not be a temperature difference because the air is not still. Mixing these air layers can raise the temperature near the crops by about five degrees Fahrenheit, over an area of about 10 acres, if the area is flat.

The exact temperature change depends on the difference in temperature and the effectiveness of the wind machine (Parsons and Boman, 2009). Wind machines are sometimes used on blueberries in Florida. However, they are not used very often because of the high probability of windy freezes (Williamson, Lyrene and Olmstead, 2012).

Growers can also use (temporary) polyethylene-covered tunnels. Generally, crops under tunnels require no or less water for freeze protection than crops in an open field. However, production under tunnels may affect production aspects such as pollination and disease management (Williamson *et al.*, 2012). Tunnels can also deliver better quality crops, and advance the harvesting time, which means higher prices if growers beat competitors to market (Bielinski, Salame, Whidden and Moore, 2011). Row covers are generally reusable. However, it can be cumbersome to cover large fields (*Ibid*.).

3.3.4.2 Costs

The average wind machine costs $30,000 and can be used on 10 acres. This price includes the machine and the cost of a concrete pad and heavy-duty bolts. When bought as a lease-purchase, spreading the cost over five years leads to an investment cost of $600 per acre assuming the grower uses the wind machine on the 10 acres. Operating costs are fourteen gallons of diesel per hour or eight gallons of propane per hour (Moss, 2013; Williamson *et al.*, 2012).

Row covers cost between $850 and $1,000 per acre depending on the thickness of the cover. There are additional costs for hoops, sandbags and the labor for putting the covers in place. It usually requires eight hours of labor to either cover or uncover one acre of land (Bielinski *et al.*, 2011). Most materials can be used for at least two or more seasons (Haman, 2010). A tunnel costs between $25,000 and $35,000 per acre (Bielinski *et al*., 2011).

3.4 Rebound Effect of Increasing Water Use Efficiency

> It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth. (Jevons, 1866, p. 123)

Increasing agricultural water use efficiency is sometimes seen as a silver bullet for freeing up water for other uses. However, several modeling studies have shown how a shift to more efficient irrigation systems does not automatically mean that total water use is reduced, and might even inadvertently increase the total consumptive water use (Huffaker and Whittlesey, 1995; Huffaker and Whittlesey, 2003; Ward and Pulido-Velazquez, 2008; Peterson and Ding, 2005; Gutierrez and Gómez, 2011). The main reasons for this are that more efficient irrigation allows farmers to increase their crop yields, change to more water-intensive crops, and expand their irrigated acreage with the water they "save", thus reducing return flows to streams and aquifers, and eventually other users.

This effect can be classified as an example of Jevons' paradox, which postulates that technological progress that increases the efficiency with which a resource is used tends to increase rather than decrease the rate of consumption of that resource (Jevons, 1866). Empirical studies that analyzed actual irrigation behavior came to the same conclusions. García Mollá (2002) reports that subsidized drip irrigation technologies in Spain did not lead to reduced application rates. Similar behavior was observed by Berbel (2005) in Spain, where adoption of drip irrigation encouraged the planting of new, more water demanding crops (as cited in Giannoccaro, Gatta, Zanni, Prosperi and Monteleone, 2008). The same outcome was seen in Crete (OECD, 2006) and in Kansas (Lin and Pfeiffer, 2010).

This issue is acknowledged by the USDA Economic Research Service (Schaible and Aillery, 2012) and the EC (European Commission, 2012). However, improving irrigation efficiency can still provide economic benefits for farmers through improved crop productivity, quality and profits (especially when combined with land leveling and more precise fertilizer and pesticide application). It can also provide environmental benefits because of reduced agricultural runoff containing harmful contaminants. Similarly, by reducing diversions, irrigation efficiency may improve environmental conditions for the water source.

Moreover, environmental scientists indicate that the rebound effect strongly depends on the hydrology of the region. The hydrology of Florida and the

Netherlands is completely different from more highly arid regions where the rebound effect has been observed. In Florida and the Netherlands aquifers are generally replenished during wet periods. However, recently minority farmers in Florida expressed their concern related to the drying up of small streams due to increased irrigation (Bartels *et al.*, 2012). Therefore we investigated the rebound effect of converting to drip irrigation in Florida. The novelty of this study is that it is based on areas that are currently seen as having a plentiful water supply for at least part of the year. Water may not be as much of a limiting factor in these areas as it is in more arid regions, and therefore the rebound effect may not occur.

Table 3-1. Irrigation systems used by horticultural growers in Florida and Limburg.

<table>
<tr><th>Type of irrigation system</th><th>Number of Florida horticulture growers in 2008</th><th>Share of Florida vegetable, fruit, field crop, ornamental and grassland in 2005</th><th>Share of Limburg horticultural field vegetable growers in 2010</th></tr>
<tr><td>Micro-irrigation</td><td>876</td><td>38%</td><td>2.6%</td></tr>
<tr><td>Sprinkler irrigation</td><td>1,763</td><td rowspan="2">19%</td><td rowspan="2">39.7%</td></tr>
<tr><td>Hand-watering</td><td>167</td></tr>
<tr><td>Sub-irrigation (seepage)</td><td>51</td><td rowspan="2">43%</td><td></td></tr>
<tr><td>Flood irrigation</td><td>72</td><td>0.03%</td></tr>
</table>

Source: adapted from USDA NASS (2010); Marella (2008); CBS (2010).

CHAPTER 4
CONCEPTUAL FRAMEWORK

4.1 Overview

This chapter gives a conceptual framework for the adoption of drought adaptation measures among field vegetable growers. Section 4.2 first describes some relevant terms. Section 4.3 reviews the main literature related to the factors that influence adoption behavior. Section 4.4 combines this information in a conceptual framework, which formed the basis for the survey research. The econometric models we used to test the conceptual framework are specified in chapter five.

4.2 Definitions

In this study we looked at how growers make the decision to adopt measures to reduce drought risk. Drought risk can be defined as the combination of the probability of drought and its consequences, which can be expressed as economic losses. This is closely related to a grower's drought vulnerability, which is the state of susceptibility to harm from exposure to drought (Adger, 2006). The size of a grower's losses depends on factors such as the duration and intensity of the drought, environmental characteristics such as soil type, the production process and crop type, and market conditions. It also depends on the grower's capacity to anticipate, resist, cope with, and recover from the impacts of drought (Adler, 2012; Jeuken *et al*., 2012). This last factor is referred to as a grower's adaptability or adaptive capacity. In other words, it is a farmer's capacity to influence the propensity of harm from drought through adaptation. Adaptation is the adjustment to a new or changing environment; in this context the action(s) taken by a farmer to moderate or better cope with the consequences of drought (Adger, 2006). As the following citation shows, it can be both proactive and reactive:

> Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. IPCC (2001, p.982)

Adaptive capacity depends on the resources available to the grower and the ability to use these resources effectively for adaptation.[5] Some traditional neoclassical economic models and some climate change studies do not include adaptive capacity (the so-called "dumb farmer" approach) but rather assume that agents do not adapt to climatic changes (IPCC, 2001). However, several studies

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[5] For example, generally speaking more investments are made to collect and store water in more intensive production systems such as greenhouse horticulture. Therefore, even though the sector has a high dependency on good quality irrigation water, it is generally less vulnerable to drought.

have shown the importance of adaptation measures in substantially decreasing adverse impacts of climate change (Ibid).

4.3 Theoretical Framework: Adoption Literature

A plethora of theoretical frameworks exist across many different disciplines that explain adoption of adaptation measures, conservation measures and agricultural innovations in general. Section 4.3.1 reviews the main theories that we identified as useful for our study. Section 4.3.2 shows how we can apply one main theory to explain adoption. Section 4.3.3 reviews the findings of recent empirical research on how well these models and their variables explain adoption. Section 4.4 follows with our conceptual framework.

4.3.1 Adoption Models

As mentioned before, the adoption literature is vast and therefore difficult to summarize. Commonly three main types of models are used to explain adoption of innovations: the adoption diffusion model, economic constraint model, and the adopter perception model (Adesina and Zinnah, 1993). We added a few other, often-used models to this discussion, but our conceptual framework is mainly based on Expected Utility Theory.

One of the earliest models to explain adoption is the influential Adoption Diffusion Model. This model was developed to explain the processes that lead farmers to accept new ideas (Rogers, 1962). Diffusion is the process of spreading knowledge of an innovation through certain channels over time among the members of a social system (*Ibid*). One of the model's advantages is that it distinguishes between five stages of adoption, whereas many other models only look at the final decision to adopt. It shows the importance of access to information about a new technology, implying that adoption can be stimulated with extension services and on-farm trials.

However, this model has been called an ‘imitation model’ as it does not pay a lot of attention to factors such as the characteristics of the adopter or the innovation besides specifying adopter categories and perceived attributes of the innovation (Zilberman, Zhao and Heiman, 2012). The model does not have a microeconomic background that explains causality. A grower is characterized according to his adoption behavior but the model does not investigate the factors that influence this behavior. In reality a person’s adoption behavior does not just depend on access to information, but on many other factors.

The Economic Constraint Model states that economic constraints such as limitations in ownership of land and capital are determinants of (non-)adoption (Feder, Just and Zilberman, 1985). The Adopter Perception Model states that the perceived attributes of a new technology determine adoption (Fliegel and Kivlin, 1966). Growers will base their adoption decision on the appropriateness of the measure in their socioeconomic and agroecological environment. This is related to the Technology Acceptance Model, which emphasizes the importance of the perceived usefulness of the measure and the perceived ease-of-use (Davis, 1989).

In this study we focus on microeconomics, and therefore we discuss a few more economic adoption models. The Farm Structure Model is similar to the Economic Constraint Model and states that larger and wealthier farms are more likely to adopt innovations (Saltiel, Bauder and Palakovich, 1994). The economic constraint model is also related to one of the earliest models to explain adoption behavior: Expected Utility Theory (EUT). It states that under risk, agents compare and evaluate the utility outcomes of all possible decisions including their probabilities of occurring, and then choose the option that maximizes their expected utility (Von Neumann and

Morgenstern, 1947).[6] The advantage of EUT is that it pays attention to microeconomics and risk. However, it is based on a number of unrealistic assumptions, such as the absence of interaction. Box 2 provides an example of applying EUT to explain DAM adoption. Psychological factors such as perceptions are also important. The Subjective Expected Utility Hypothesis (Savage, 1954) states that the probabilities of the outcomes in EUT are not objectively known beforehand, but are subjective.

Protection Motivation Theory (Rogers, 1975) also describes how socioeconomic and psychological factors influence adaptation to protect oneself from an adverse outcome. It postulates that people first evaluate the threat of not adapting in terms of the severity and the probability of the threat occurring, and then look at the ability to cope with the adverse outcome. To this end a grower will first appraise the effectiveness of the measure in reducing the drought risk and the ability to implement the measure, taking into account adaptation costs. Sometimes individuals will not adapt, because they underestimate the threat. Thus perception of drought risk and perceived efficacy of the adaptation measures are important factors. Figure 4-2 summarizes the theories.

4.3.2 Applying Expected Utility Theory to Explain Adoption

This sections draws from a study done by Koundouri, Bauges and Tzouvelekas (2006). We assume a grower produces a certain output, *q*, with a technology described by a well-behaved (continuous and twice-differentiable) production function, *f(.)*. We denote the price of the output as *p*, ***X*** as the vector of conventional inputs, X_w as the input of water, and ***r*** as the vector of the prices of the

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[6] Provided that the preference relation is a complete and transitive relation that satisfies the independence and continuity axioms.

conventional inputs. We assume that the grower faces the risk of reduced crop yields due to drought and increased water demand. We can represent the risk of damage due to reduced water availability as a random variable, ε, whose distribution *G(.)* can be affected by farmer actions. Irrigation technology varies in its level of efficiency and this is reflected in the scaling parameter $h(\alpha)$, $0 \leq h(\alpha) \leq 1$. The total amount of effectively used water becomes $h(\alpha)X_w$.

Then we can formulate the production function as $q = f\,[h(\alpha)\,X_w, \boldsymbol{X}]$. Growers are assumed to be price takers for both inputs and output. The grower's problem is then to maximize the expected utility of profit, while incorporating the risk preference:

$$max\,E[U(\Pi)] = \max_{X,Xw} \int [U(pf(\varepsilon, h(\alpha), X_w, \boldsymbol{X}) - r_w X_w - \boldsymbol{r'X})]dG(\varepsilon, \alpha) \tag{1}$$

where *U(.)* is a Von Neumann-Morgenstern utility function. With the first order conditions we can derive the optimal water input X_w^*.

We assume that the grower can choose to adopt (*A=1*) or not (*A=0*) a DAM that would increase the on-farm water use efficiency, increasing $h(\alpha)$ such that $h^1(\alpha) > h^0(\alpha)$ for $0 < \alpha < 1$. This will reduce the risk of yield losses during a period of drought or increased water demand. We also assume that the future costs and benefits of the DAM are known at the time of adoption. Then adopting the DAM implies a fixed cost ($I^1 > 0$ and $I^0 = 0$) and might change the marginal cost of water ($r_w^1 \neq r_w^0$). The grower will adopt the DAM if the expected utility with adoption is greater than the expected utility of non-adopting. This leads to two maximization problems:

$$\max_{x^1, x_w^1} \int \{U[pf(\varepsilon, h^1(\alpha)x_w^1, \boldsymbol{x}^1) - r_w^1\, x_w^1 - \boldsymbol{r'x}^1 - I^1]\}\, dG(\varepsilon) \tag{2}$$

$$\max_{x^0, x_w^0} \int \{U[pf(\varepsilon, h^0(\alpha)x_w^0, \boldsymbol{x}^0) - r_w^0\, x_w^0 - \boldsymbol{r'x}^0 - I^0]\}\, dG(\varepsilon) \tag{3}$$

And again we can take the first order conditions to determine optimal water input. A grower will compare the expected utility of both choices and choose the technology with the higher expected utility.

4.3.3 Empirical Adoption Studies

Many empirical studies have tested these theories to see which variables explain adoption of measures such as conservation tillage, BMPs in general, irrigation, or climate change adaptation measures. Other studies have used meta-analyses to summarize these findings.

It is important to note that the DAMs that farmers have adopted may be driven by other considerations than (expected) increases in meteorological drought and water demand. However, farmers in the studies by Maddison (2007) and Nhemachena and Hassan (2007) stated that their actions were climate change driven. Moreover, in our study, we asked growers about their perception of water availability and drought, to see if there was a correlation between drought perception and adoption of DAMs. However, this does not guarantee causality. Therefore this is one limitation of the study: adoption of some of the measures may not have the primary goal of drought adaptation.

4.3.3.1 Adoption of agricultural innovations in general

Most studies investigating determinants of adoption include demographic, farm and institutional characteristics. Therefore, we briefly describe the results related to these variables. Knowler and Bradshaw (2007) conducted a meta-analysis of adoption of conservation tillage and do not find a clear connection between adoption rates for conservation tillage and variables such as age, education, or environmental awareness. They concluded that, with the exception of social capital, it is impossible to find any universal variables to explain adoption of conservation tillage. Lockeretz (1990) observed the same and suggested we look beyond the traditional farmer, institutional, and farm characteristics and pay more attention to the complexity inherent in the motivation to participate in conservation programs.

Prokopy, Floess, Klotthor-Weinkauf and Baumgart-Getz (2008) conducted a meta-analysis of studies on BMP adoption in the United States for all types of BMPs. They find that education levels, capital, income, farm size, access to information, positive environmental attitudes, environmental awareness, and utilization of social networks are often positively associated with adoption rates. They also state there have been mixed results on the effect of *gender* on adoption. Out of the 55 studies they reviewed, only three considered gender. Of these three studies, two studies found no significant effect of gender on adoption and one study found being male has a positive relationship with adoption (*Ibid*.).

While the measures we looked at usually do not serve the primary goal of being environmentally friendly, the majority conserve water use and may appeal to growers who are also interested in environmental protection. Generally in the literature, women are hypothesized to be more concerned for the natural environment than men. Zelezny, Chua and Aldrich (2000) reported six of nine studies found significant women expressed greater concern than men.

However, there have also been reviews that show less of a relationship between gender and environmental concern (Hines, Hungerford and Tomera, 1986-87; VanLiere and Dunlap, 1980). Several studies on adoption of conservation practices in agriculture found female farmers in Tanzania, the UK, and Haiti to be more likely to adopt conservation practices (Newmark, Leonard, Sariko, and Gamassa Deo-gratias, 1993: Burton, Rigby and Young, 1999; Dolisca, Carter, McDaniel, Shannon and Jolly, 2006). Additionally, in climate change adaptation, gender differences could play a role. Alston (2011) describes the gender differences in adaptation to climate change in Australia, specifically to increased drought problems. Since gender differences in both motivations to adopt DAMs are said to exist, we decided to also include gender in our model, hypothesizing that females are more likely to adopt DAMs.

The effect of a farmer’s age on adoption has regularly been studied. According to the theory of human capital, young members of a household have a greater chance of absorbing and applying new knowledge (Sidibé, 2005). However, empirical studies show mixed results, including positive, negative and insignificant correlations (Prokopy *et al.*, 2008; Knowler and Bradshaw, 2007). For experience the literature shows both positive and insignificant correlations (*Ibid.*; Prokopy *et al.*, 2008). Many studies indicate a positive correlation with education level and adoption behavior. In most adoption studies farmers with higher levels of educational attainment are more likely to adopt new technologies or practices than less educated farmers (see for example Neupane, Sharma and Thapa, 2002). However, negative and insignificant correlations have also been found.

Many studies hypothesize that size matters, as larger and wealthier operations are more willing to invest in new technologies (Prokopy *et al.*, 2008). Adoption of a new technology requires sufficient financial means, especially if it requires the purchase of equipment, thus entailing sunk costs. For a larger operation, the investment cost for equipment that can be utilized over the entire farm as well as the non-monetary time cost of learning about the new technology will be lower per acre than smaller operations. Additionally, larger farms are likely to be more able to bear risks associated with early technology adoption (Feder *et al*., 1985). In the majority of studies, the relationship between farm size and the probability of adoption is positive, but some indicate negative or insignificant relationships (for examples see Knowler and Bradshaw, 2007).

The mixed results of previous work posed a challenge for our study. We decided to consider variables included in previous analysis as well as additional variables that have not been thoroughly analyzed yet. For example, Lockeretz (1990) stressed that there is a need for more research focusing on spatial patterns. Adoption decisions are affected by land characteristics, which means the spatial distribution of adoption is important. Also, the diffusion of adaptation measures may have a spatial component when there is spatial “contagion” through the spread of information on new technologies (Ervin and Ervin, 1982).

For example, Case (1992) concluded there is a spatial lag structure in the distribution of opinions on technology adoption amongst Indonesian farmers. Propoky *et* al. (2008) suggested that more research is needed pertaining to farm proximity to a river or stream.

Most studies looking at adoption of adaptation measures or efficient irrigation systems refer, in their literature review, to studies on adoption of innovations in general. We did the same in this section. However, we are also interested in what we can learn from studies that focused specifically on the adoption of efficient irrigation or climate change adaptation measures.

4.3.3.2 Adoption of more efficient irrigation

Studies on adoption of efficient irrigation technologies at the farm level generally use logit or probit models to explain adoption at one point in time as a function of its expected utility compared with the utility obtained from the alternative situation. This body of literature spans the adoption of different types of irrigation technologies (mainly drip irrigation), in the geographical regions Hawaii, California, Tunisia, Spain and Israel. These studies used probit models, multinomial logit models, duration analysis and F-tests.

Shrestha and Gopalakrishnan (1993), in a study of 450 sugarcane fields in Hawaii, analyze the adoption of drip irrigation. Their model includes variables related to the physical (engineering and agronomic) aspects, including yield per acre, amount of irrigation water (plus the same variable squared) and fertilizer applied, age of crop at harvest, cane variety, and planting method. They also include locational characteristics such as water holding capacity of the field, field gradient, soil order, and field size. Additionally, they include economic variables such as sugar price, and the expected differential in water use and yield from drip adoption. They used a maximum likelihood probit to test their model. They find that the expected increase in crop yield, as well as acreage, plant cycle, a lower temperature, and having a Mollisol or Oxisol soil,[7] all increase the probability of adoption while the expected change in water use decreases the probability of adoption. The outcome for the soil type was surprising to the authors, since they are both good quality soil types. Therefore the hypothesis that drip is more likely to be adopted in poor-quality lands does not seem to hold here. However, adoption was slightly higher on the high quality land with the lower water holding capacity. Shrestha states as a response to this that the outcome depends on the main motivation to use drip: for yield increases or for conserving water. This study did not explicitly include farmer characteristics, but had a farm field as level of analysis.

Green, Sunding, Zilberman and Doug. (1996) also explained adoption at the field level in California, in a study of 1,493 fields cultivated by 350 citrus, deciduous,

[7] Mollisols (which can also be found in Florida on a limited scale) are a soil order in the soil taxonomy which are highly fertile, high in calcium, clay and organic matter. Oxisols, on the other hand, also have good physical properties but have poor water-holding capacity (they infiltrate and percolate very fast) and low fertility.

and grape growers, where they analyze the adoption of three types of irrigation: traditional or gravity technology (flood, furrow), high-pressure sprinklers, and low-pressure systems like drip and micro-sprinklers. They include economic and environmental farm characteristics such as water price, use of surface water, soil permeability (in inches per hour), field slope and size, and three crop types.

They use a multinomial logit model which is estimated with maximum likelihood. They find that crop type is important: growing a perennial crop increases the probability of adopting drip and decreases the adoption of sprinkler irrigation. They also find that water price positively influences adoption of drip and negatively influences adoption of the other irrigation categories. This makes sense since drip irrigation has lower water losses. Additionally, they find that land quality variables, i.e. soil permeability and field slope are important. Drip irrigation adoption is positively influenced by field slope. It allows for cultivation of irrigated crops on lands with steep slopes that had previously been unproductive. Soil permeability and slope have a large positive effect on the probability of adopting furrow and drip irrigation. Also this study did not look at characteristics of the grower.

Foltz (2003), in a study of over 100 growers of a variety of crops, including strawberries in Tunisia analyzes the adoption of drip irrigation with a probit model. The explanatory variables include the amount spent on water in the previous year, salinity of irrigation water, monthly household expenditure per person, the ability to borrow money, the number of years since the grower first heard of drip, level of education, farm size, an index measure for crop diversification, and the percentage of land owned and percentage of land in strawberries. The study also included a dummy variable for a region within the study area within a certain radius of where the technology was first introduced. The reason for this was to prevent attribution of adoption behavior to crop choice rather than the underlying variables that are correlated with that crop choice. Therefore a restricted and unrestricted model were estimated. The first model ignores the type of crops a farmer grows, while the second uses the percentage of land devoted to strawberries as an explanatory variable. This did slightly alter the coefficients. Expenditure on water in the previous year, the ability to borrow money, and the number of years since a grower saw drip increase the probability of adoption. There were no variables with a significant negative effect on adoption. The regional dummy is significant, indicating that there could also be regional differences or a spatial diffusion effect. Our study was similar to this study, since we looked at many of the same explanatory variables.

Alcon, Miguel and Burton (2011), in a study of 360 vegetable, citrus, and fruit growers in Spain, analyze the adoption of drip irrigation with discrete time models.[8] The dependent variable is the time between the moment a farmer begins to manage the farm or the year the technology is available (whichever is latest) and the year the farmer implements this technology on his farm. The independent variables can be categorized as the identification of the innovation-decision process (knowledge, persuasion, decision, implementation and confirmation), personal characteristics of the farmer (age, education level, being a member of a cooperative), economic factors (number of household members working on the farm, a dummy for on-farm income as the main source of household income; water price, credit availability), characteristics of the farm (acreage, dummy for fruit), under management and technology characteristics (dummy for grower having tested technology, main

[8] The authors use duration analysis, a statistical method based on biometrics and statistical engineering that studies the expected time an individual spends in one state before transitioning to another.

information source, groundwater allocation, adoption in the year prior to Spain becoming a member of the European Union in 1986).

The authors find that education level, being a member of a cooperative, water price, access to credit, growing fruits, source, and information increase the probability of adoption while age decreases the probability of adoption. There was also a positive effect of water availability or allotment, which was unexpected since generally less water is hypothesized to induce adoption. The European Union variable was also a significant positive influence on adoption, which was explained as the expected increase in market prices after entry, which could justify adoption of drip irrigation. Age was shown to reduce the probability of adoption.

Dinar and Yaron (1990), in a study of 209 citrus growers in Israel, analyze the adoption of sprinkler, microsprinkler and drip irrigation with through OLS regressions. They looked at the effects of variables such as soil, water, and rootstock quality, water price, and various regional conditions, as well as human capital, management, and scale of the operation on the percentage of grove acreage with modern irrigation technologies and the percentage with drip irrigation. They find that evaporation rates, sensitivity of the rootstock, conditions of restricted water allotments and higher water prices positively influence the probability of adoption of modern irrigation technologies. Also, land quality negatively influences this adoption.

The factors influencing adoption may also be location-specific. Hodges, Lynne, Rahmani and Casey (1994) stated that in Florida, factors that may affect adoption of conservation irrigation technology include crop characteristics, the financial situation of the farm, resource characteristics (such as soil and water), grower characteristics (education, experience), farm tenure (owned versus leased land), costs of the technology, and institutions such as WMD rules on efficiency of agricultural water use.

4.3.3.3 Adoption of climate change adaptation measures

This body of literature spans the adoption of different types of climate change adaptation measures in African countries and Colorado. These studies used Heckman probit models, multinomial logit models, and a multivariate discrete model to explain adoption.

Maddison (2007), in a study of 9,500 growers in 11 countries in Africa, analyzes the adoption of climate change adaptation measures. He includes variables such as farming experience, extension advice, distance to input and output markets, being a subsistence farmer, age, education, gender, marital status, farm size, proportion of land owned, temperature, and precipitation. Using a Heckman probit model, he first analyzes the probability that a grower perceives climate change as a threat, and then the decision of whether or not to adopt technology to mitigate climate change risk. He finds that non-adoption is positively influenced by distance to selling market, being a subsistence farmer, precipitation, percentage of land borrow, and living in Burkina Faso, Ghana, Niger or Senegal. Non-adoption is negatively influenced (so adoption is positively influenced) by farming experience, extension advice, education, being a male, being married, farm size, temperature, and living in Cameroon, Egypt, Ethiopia, or Kenya (Maddison, 2007).

Deressa, Hassan, Ringler, alemu and Yesuf (2008), in a study of 1,000 households in Ethiopia, analyze the adoption of climate change adaptation methods. Their model includes variables for education, household size, gender and age of the head of the household, farm and nonfarm income, livestock ownership, information on climate change, farmer-to-farmer extension, access to credit, farm size, distance to input and output markets, dummies for agro-ecological regions, temperature and precipitation. Using a multinomial logit model, they find that education, the household head being a male, farm income, farmer-to-farmer extension, credit availability, and temperature increase the probability of adoption of conservation measures, while precipitation has a negative influence. For adoption of different crop varieties only being a male and education had a positive influence on adoption.

Hassan and Nhemachena (2008), using a dataset that is partially the same as that of Maddison (2007), analyze adoption of climate change adaptation measures (including different crops and varieties, crop diversification, different planting dates, irrigation, water conservation, and switching to non-farming) among 1,719 growers in South Africa, Zambia and Zimbabwe, by using a multivariate discrete choice model. They looked at characteristics such as gender and age of the household head, household and farm size, farming experience, access to free extension services, electricity and credit, temperature and precipitation, being a subsistence farmer, having noticed climate change, having animal power, a tractor or heavy machines, per capita income, and farm ownership. The outcome of their study showed that extension services and farming experience had significant positive effect on adoption for almost all adaptation measures.

Female headed households were more likely to adopt adaptation measures, with the largest coefficients for the different crop varieties suitable to predicted climatic conditions, and increasing water conservation. Electricity, being a subsistence farmer, access to credit, distance to the selling market, having noticed climate change, and mean annual temperature positively influenced the probability of adoption of all adaptation measures. Precipitation was shown to have a negative influence on the probability of adopting irrigation, water conservation or non-farm activities, while it positively influenced the probability of growing climate change resistant crop varieties. Having a tractor or heavy machinery positively influenced adoption of nearly all measures, and so did animal power except for switching to non-farm activities, where the variable was insignificant and negative. Farm ownership was a determinant for adoption of all measures except for different crops and crop varieties that are better suited to the expected climatic changes (Hassan and Nhemachena, 2008).

Schuck, Frasier, Webb, Ellingson and Umberger (2005), in a study of 1,100 agricultural producers in Colorado, analyze the adoption of efficient irrigation systems after the worst drought ever recorded in Colorado, which occurred in 2002. They use a multinomial logit model and look at the influence of variables such as acreage, acreage of corn and hay specifically, education, income from agriculture, level of education, and irrigation system before drought. The outcomes are the proportion of land irrigated with flood irrigation, gated pipe irrigation (we do not look at this type of irrigation since it is not commonly used in Florida or Limburg), and sprinkler irrigation.

The proportion of income derived from agriculture reduces the probability of adoption of gated pipe irrigation. Also, if an individual changed irrigation technology as a drought response, they were more likely to increase the proportion of land irrigated by gated pipe than those growers who did not change their irrigation system due to drought.

The prevalence of sprinkler irrigation was most significantly affected by land tenure, cropland acreage and level of education. Renting or leasing land reduces the probability that sprinkler irrigation is adopted. A landowner’s incentive to invest in irrigation may be less if the benefits are to be shared with a tenant. Education and acreage positively influences the proportion of land under sprinkler irrigation. The study also looked at hay and corn acreage specifically, where the latter requires more intensive management. Corn acreage positively influenced adoption of sprinkler irrigation.

In our study we did not focus solely on climate change-induced drought, but also on the effects of population growth, increasing water consumption as wealth increases, etc. Moreover, climate change is a sensitive topic in Florida. Still, these models give us information on the types of factors that could influence adoption from an adaptation perspective.

4.4 Conceptual Model for Adoption of DAMs

This section combines the insights of the theories and the variables described above in a conceptual framework, which formed the basis for the survey. The specific independent variables used in the models are listed and defined in Section 4.4.3: Explanatory Variables.

In Florida and Limburg, climate change and population growth increase drought risk for field vegetable producers. High quality water is an important input for agricultural production; reduced water availability can lead to reduced crop yields and quality. There are several measures that growers can adopt to reduce their vulnerability to drought. Our conceptual model consists of several variables and relationships that explain the decision to adopt drought adaptation measures, as well as the intensity of adaptation through the number of measures adopted.

We assume that a grower will adopt a certain measure if the perceived benefits of the measure are greater than the perceived costs, subject to constraints. The benefits and costs depend on the grower's perception of the drought risk. This means that the benefits of the measures are interpreted differently by different growers. For each measure we can state that the expected utility a grower gets from adopting technology *i* is a function of the variables summarized in Table 4-1. Adoption will occur when the expected utility obtained from adopting technology *i* exceeds the expected utility from adopting no technology and/or exceeds the expected utility from adopting all other substitutable technologies. Expected utility for technology *i* is given as:

$$EU = u\ (G, F, R, E, I, P) \tag{4}$$

where the abbreviations refer to the vectors of variables described in Table 3. Growers may also bundle technologies. In this case, the expected utility of the bundle of technologies exceeds the expected utility of all other possible bundles.

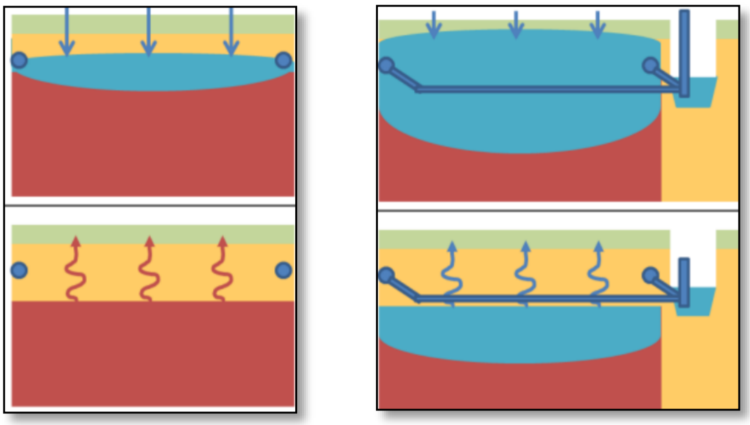

Figure 4-1. The effect of WLSAD.
Source: Tolk (2012).

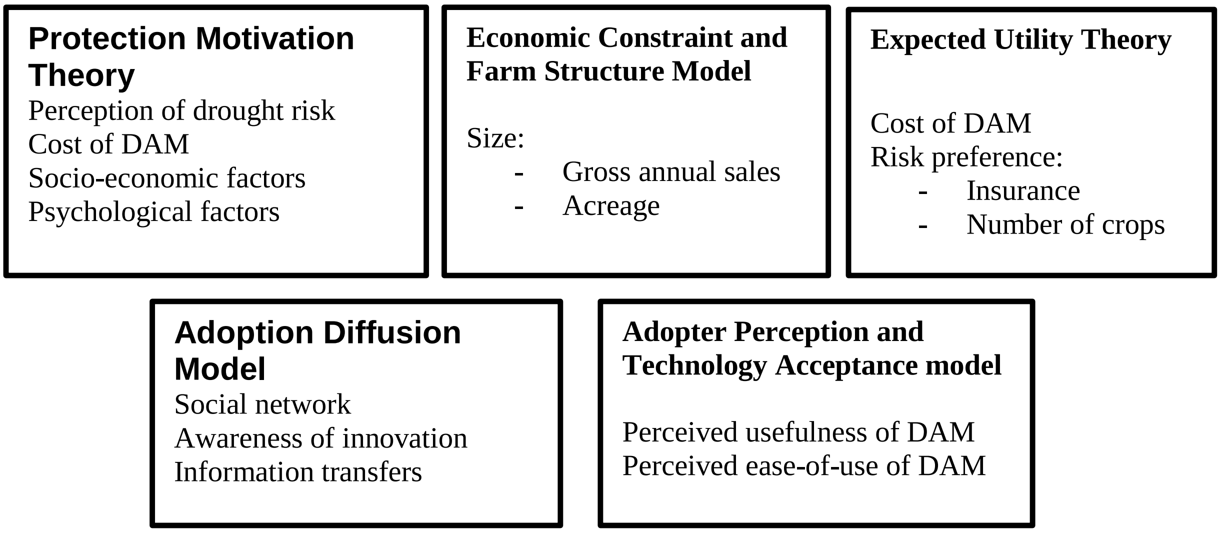

Figure 4-2. Theories on determinants of adaptation.

Table 4-1. Variable categories of our conceptual model.

Variable category	Variables
Grower demographic variables	Gender, age, farming experience, education level
Farm and economic variables	Size (gross sales, acreage), tenure, crop type
Drought risk perception and risk preference variables	Perception of predictability of water supply and future water availability, risk preference (insurance, number of crops)
Environmental and spatial variables	Soil type, presence of a stream, attitude of neighbors, having experienced shortage with or without damage in the past, having been asked to cutback water use.
Institutional variables	Being enrolled in a cost-share program, having used extension services (MIL)
Perceived attributes of measures	Perceived effect of DAM on costs, difficulty, yields and labor requirements.

CHAPTER 5
DATA AND METHODOLOGY

This chapter describes the development, pre-testing and distribution of the survey. It also gives a description of the empirical models used for the survey analyses, and a summary of the variables we included and their descriptive statistics. We did not have sufficient data to do a quantitative test for the rebound effect of converting to drip irrigation on consumptive water use. We therefore do not describe any models for this topic in this chapter. Chapter six continues with the results of the analyses, which includes descriptive statistics related to the rebound effect.

5.1 Survey Development, Pre-testing, and Distribution

One of the main components of this study was the design and analysis of an online survey. The complete survey is presented in Appendix A. This section describes the process of designing, pre-testing, and distributing the survey.

5.1.1 Survey Development, Design, and Testing

To guide the development of the questionnaire, informal interviews were conducted with horticultural and economic scientists from the University of Florida (UF). Additionally, we consulted extension workers from UF's Institute for Food and Agricultural Sciences (IFAS), a former administrator of the Office of Water Policy in FDEP, people from the Dutch agriculture and horticulture organization, a policy administrator from an RWA, and two experts from the Delta Plan for High Sandy Soils.

The survey design was largely based on the Dillman method (Dillman, 1991). Due to limited availability of funds, and since the University of Florida does not allow lotteries or raffles to be used as incentives, this study did not use any significant incentives to stimulate participation. We aimed to reduce non-response error by giving a small material incentive in the form of a bookmark to the growers in Florida who were sent a letter. Moreover, we stressed the study's social usefulness and why the respondent's participation was important, as well as the benefits of this research to the respondent. We assume that most respondents (at least in Florida) associated themselves with the topic of the survey, as several Floridian farmers informed us that the topic of the survey is an increasingly pressing issue.

The survey was designed to take a maximum of fifteen minutes (which it took according to the survey results), with user-friendly answering methods and a pleasant layout. Personal questions were saved for the end of the survey. To deal with the risk of item non-response we did not include a 'don't know' option (except for one question), but stated at the beginning of the survey that the respondent can skip questions.

We tried to make sure that the wording of the survey was understandable and the skip patterns automatic and easy. We mainly used closed-ended questions to increase the response rate, even though this increased the risk of position bias. To deal with the risk of missing response categories we occasionally gave respondents the option to choose the category "other" with space to write in a response.

Measurement error, or the discrepancy between underlying, unobserved variables and observed responses, can result from respondent characteristics (e.g. unwillingness to give accurate information) or survey design (question wording, order). To deal with this we tried to avoid sensitive topics, intrusive questions, and we tested the survey at two farmers markets in Gainesville, Florida, where three growers pretested the survey. Since we targeted farmers, which is a relatively old age group, we did not use small print to ensure legibility. For the purpose of this study, the farm manager was assumed to be the sole decision maker although we did ask about the influence of a landlord in the case of leased farmland.

5.1.2 Survey Distribution

Unfortunately the timing of the survey was not ideal, as it was sent out during a very busy time for growers in both Florida and Limburg. It was, however, sent out during the driest part of the production season in both areas, which may have increased response rates because of the relevance of the issue at that time. For both regions the survey was distributed using multiple channels.

5.1.2.1 Survey distribution in Florida

In Florida the survey was cross-posted by the Florida Farm Bureau (FBB) in an e-mail to their members, in e-mails and digital newsletters by 20 of Florida’s 63 IFAS extension offices and several multi-county agents, and in a letter to growers who have expressed interest in BMPs with the Florida Department of Agricultural and Consumer Services (FDACS). One IFAS extension office distributed printed copies of the survey from their booth at the local farmers market. Each organization was given a separate URL. This allowed us to use the name of the organization on the first page, which respondents could recognize and which we hoped would increase the response rate.

The largest group of respondents consists of growers that were contacted through the FDACS list. The growers in the FDACS sample frame were sent a personalized invitation letter to ask for their participation in the online survey. The letters, and later postcards, asked the respondents to go to the survey website and enter their individual access code which was given to them on their letter. This access code prevented us from sending reminders to growers who had already taken the survey. It also made it possible for us to shorten the survey because knowing the respondent’s address enabled us to obtain spatial data such as soil type and distance to the nearest water body without having to ask for it.

This spatial information also would have enabled a more elaborate spatial analysis if it had not been for the large share of post office box addresses.[1]

The salutation included the name of the respondent, the letter had a clear UF IFAS logo and was personally signed. It explained the use of identification numbers and how confidentiality is protected. In accordance with Dillman's (1991) recommendation, we used four carefully spaced mailings:

- Cover letter and invitation to participate in the online survey
- Postcard follow-up one week after the original mailing,
- Second cover letter informing the recipient the questionnaire had not yet been received four weeks after the original mailing
- Second postcard reminder seven weeks after the first mailing

The average response time in online surveys is 5.59 days, compared to 12.21 days in mail surveys (Ilieva, Baron and Healey, 2002). This implied that follow-ups could be sent earlier. After taking the survey, respondent names were taken off the list and did not receive any more reminders. Table 5-1 shows the number of responses from the FDACS list after each mailing.

5.1.2.2 Response rate

Table 5-2 summarizes the response rates for all surveys distributed in Florida. The response rate was determined as the percentage of people contacted that submitted complete responses (with over 80 percent of basic questions answered) and who were part of the target audience (some respondents did not meet this requirement). The table also shows the percentage of surveys that was returned

[1] Out of the 62 usable FDACS responses 13 respondents had post office addresses. Fortunately we were able to recover farm addresses for four of these respondents through online searches, so we ended up with 53 usable addresses. However, some of them were located in residential areas, in which case the spatial information was not entered, reducing the number of usable responses.

including incomplete responses or responses which were not part of the target audience.

The response rate of the FBB requires some explanation. The Bureau sent an e-mail to 968 vegetable producers and 274 producers of ornamental plants to ask them to participate in the survey. 255 producers opened the e-mail. We do not know if those who did not open it did not do so because they no longer use those email addresses, if the email was directed to spam folders, if they always delete FFB emails without reading them, or if there was a different reason. The FFB records indicate that 85 people clicked the link to the survey. Of this group, 58 people answered at least one question (four people selected the option "no I do not want to participate or am under the age of 18). Of these 58 people, 46 respondents answered a sufficient number of questions to be included in the analyses. Consequently, we only consider those who opened the email when calculating the response rate. This results in an 18.1% response rate which exceeds the response rates of several recent producer surveys which ranged from 11 to 13.2 percent (An, 2009; Goodhue, Heien, Lee and Sumner, 2002; Grogan and Goodhue, 2012).

However, the overall response rate is shown to be 11 percent. This may have been because no compensation was offered for participation. Additionally, some respondents may have found the survey too long, as approximately two thirds of the respondents quit halfway through. Moreover, there are several reasons why the overall response rate stated here is only a lower bound.

First, in some cases the response rate was difficult to determine, because it was not clear how many people were successfully contacted. Generally, there will be e-mails that bounce, and some growers may always delete emails from their extension agent, regardless of content. However, we did not have information on the number of incorrect e-mail addresses or e-mails opened (aside from FBB emails).

Second, some growers have potentially been contacted by multiple entities with each contact being counted as different individuals since overlap between entities distributing the survey was unknown. This over estimates the number of growers contacted. At the same time, the survey was sometimes inadvertently sent to producers of other commodity categories, such as fruits, arable crops and livestock. These two sources of error in the total number of invited participants work in the opposite direction, but the relative magnitude of the errors is unknown.

Finally, in 2007 Florida had 1,493 commercial vegetable farms according to the Census of Agriculture (USDA NASS, 2007). The summation of the number of people invited for the survey indicates that 1,502 farmers could potentially have been invited to participate in the survey. Keeping in mind the possible overlap between distributors in terms of the growers they contacted, the total number of invited participants stated in the table likely overestimated the number invited.

5.1.2.3 Survey development and distribution in Limburg

The survey in the Netherlands was adapted to local circumstances by talking to local horticultural experts. This gave interesting insights into the different drought adaptation measures that are being considered in the Netherlands. It was decided to focus the research on one of the twelve provinces of the Netherlands, Limburg, because of its similarities with Florida in terms of soil type and crops produced. It is an important field vegetable production area with deep sandy soils and drought is often a problem in this region. The Limburg Agri- and Horticulture Association (In Dutch: LLTB), which has contact with between 60 and 70 percent of the vegetable producers in this region, sent the survey URL twice in their weekly digital newsletter and also put the URL on their website. We assume that the newsletter was sent to a total of 1,217 growers. However, this an upper bound which also includes arable producers and potato growers.

The URL and the call for participation were also included in the newsletters and websites of some of the main online knowledge platforms for agriculture in the Netherlands: www.groentennieuws.nl, www.agf.nl, www.kennisakker.nl, and www.gfactueel.nl. We do not know how many people were potentially contacted by putting the survey URL on these websites.

When the response rate was low, we requested the company identification numbers of field vegetable growers in Limburg (under which the vegetable growers are registered with the Dutch national government) from the Agricultural Economics Research Institute (LEI Wageningen UR), which was involved in this study and regularly does analyses based on the national agricultural census. We then used these numbers to obtain the grower addresses at the DienstRegelingen, after explaining the benefits of the study.[2] Due to limited time, a letter was sent only once to 369 field vegetable growers, asking them for their participation in the online survey. Before the letter was sent, 24 people had started the survey of which five led to usable responses. After the letter was sent an additional 17 people started the survey, but only 11 gave us usable responses. As Table 5-2 shows, this leads to a low response rate, which is the reason that we only provide a descriptive analysis of the results for Limburg.

[2] DienstRegelingen is a digital public service provider that administers national and international regulations on behalf of the Dutch Ministry of Economic Affairs.

5.1.3 Considerations Related to Internet Surveys

Access to internet should not have been a problem in the Netherlands, which has a 92.9 percent penetration rate (Internet World Stats, 2013). In Florida, on the other hand, rural household access was 65 percent in 2007 (*Ibid*.), although it has been reported that rural internet access in Florida has increased quickly in recent years. We also gave participants the option of requesting a paper version,[3] and extension offices offered growers help in completing the survey in their office.

In online surveys the absence of an interviewer reduces the likelihood both of socially desirable responses and of interviewer subversion (Dillman, 1978). However, despite the confidentiality statements and protocol, growers may still have been suspicious of confidentiality issues. Also, technical issues such as browsers that do not have sufficient capacity to view the survey website may have caused problems. One respondent e-mailed us to inform us that he could not open the shortened URL. Other growers might have had the same problem but not gone through the effort of contacting us to obtain the original URL or a paper version.

5.2 Empirical Model for Adoption of Drought Adaptation Measures

This section describes three econometric discrete choice models to explain adoption of DAMs that were tested with empirical data from Florida: an ordered probit to study the choice for the irrigation system, a bivariate probit that we used to determine the factors influencing adoption of two categories of DAMs; and an ordered probit to study the determinants of the number of measures. The rationale for our choice of models is described in sections 5.3.1 through 5.3.4.

[3] We are aware that using mixed modes (such as both online and paper versions) may impact responses. Taken strictly, the results from the two modes cannot be treated as equal because of differences in *who* responds (i.e., non-response bias) and in *how* they respond (i.e. response bias). For our research only the last error might have occurred, but we ignore it in this study since we only had three paper versions.

5.2.1 Focus on Individual or Multiple Measures

There are several options for analysis. The main question is whether to analyze adoption of DAMs individually or to jointly analyze adoption of multiple DAMs.

Many adoption studies assume that adoption decisions are made independently of one another. However, by focusing on the adoption of only one measure these studies neglect the effect of scale across measures and the influence of adoption of one DAM on adoption of another DAM.

Error terms are often correlated because of complementarities (positive correlation) and substitutabilities (negative correlation) between different options (Feder *et al.*, 1985; Rogers, 1995; Belderbos, Carree, Diederen, Lokshin and Veugelers, 2004).

Positive correlation can also be caused by unobservable farm-specific factors such as indigenous knowledge that affect the choice of several adaptation options. It therefore seems better to treat DAM adoption as a joint decision. A grower's total utility of adopting more than one measure might not be equal to the sum of their separate utility effects (Park and Lohr, 2005).

Other studies look at adoption of multiple measures but treat them individually by running a separate regression model for each measure. However, non-adopters may have reasons to not adopt any DAMs. Among our respondents the average number of DAMs adopted by growers who showed adoption behavior was 3.15 DAMs, and 17 growers did not apply any DAM. Therefore we did not want to do a regression for each DAM separately. This also seems to indicate that cost-share programs provide a holistic adaptation plan. Napier, Tucker and McCarter (2000) mention that separate analysis of measures leads to measurement errors and is a possible reason for the lack of understanding of adoption behavior.

However, analyzing the scale of DAM adoption across multiple measures can also lead to problems. Using the number of DAMs adopted as the dependent variable assumes that all DAMs could technically be adopted. It also assumes that adoption of one DAM does not hinder the adoption of another DAM, which can be unrealistic in the case of, for example, different irrigation systems. Also, the determinants for DAM adoption may vary across practices.

5.2.2 Probit and Logit models

The probit model estimates the probability that an event occurs. There is an unobservable (latent) variable y_i^* (such as net utility from adoption of a DAM) with the following regression relationship:

$$y_i^* = \beta' x_i + \varepsilon_i \tag{1}$$

While the utility obtained is not observed, the actions of the grower are observed. The observable variable, *y*, equals 1 if the DAM is adopted and 0 otherwise. The probability of adoption is given by:

$$Prob(y_i = 1|x_i) = F(\beta' x_i) \tag{2}$$

where *F(.)* is the cumulative distribution function (CDF) of y_i^*.

When the CDF is assumed to be the standard normal distribution, the parameters, β, can be estimated by maximum likelihood.

The log-likelihood function is then:

$$LL = \sum_0 ln[1 - F(x_i'\beta)] + \sum_1 ln[F(x_i'\beta)] \tag{3}$$

If we would instead assume that the error term has a logistic cumulative distribution, we would have a logit model.

Probit and logit models are the most commonly used models in the analysis of agricultural technology adoption (Prokopy *et al.*, 2011). Both models are quite similar, the main difference being that the logistic distribution has slightly fatter tails. The models only produce different results in very rare situations, such as when there are very few positive or negative responses (Greene, 1997). Agresti (1996) notes that it would require very large sample sizes to have significant differences between the two models.

Using a univariate technique such as probit analysis to model each of the adaptation measures individually as functions of a common set of explanatory variables is prone to biases caused by ignoring common factors that might be unobserved and unmeasured and affect the different adaptation measures. It fails to take into account the relationships between adoption of different adaptation measures. Farmers might consider some combinations of adaptation measures as complementary and others as competing. By neglecting these common factors the probit model ignores potential correlations among the unobserved disturbances in adaptation measures, and this may lead to statistical bias and inefficiency in the estimates (Lin, Jensen and Yen, 2005; Belderbos *et al*., 2004). However, it is still the most useful model for us to look at the determinants of the growers' adoption of the two types of drought adaptation measures.

5.2.3 Ordered Probit

Ordered probit regressions are useful for studies involving an ordinal dependent variable. In our study this is the case for the adoption of irrigation. The outcome variable has several values representing an ordinal scale from least efficient irrigation system to most efficient irrigation system where growers who do not use any irrigation system were eliminated from the analysis. We also used this model to analyze the factors influencing the number of measures adopted.

Similar to the probit model, there is an unobservable variable, y^*. In our case, this variable is the utility that the grower gets from the level of irrigation efficiency or the number of DAMs implemented.

$$y^* = \boldsymbol{x}'\beta + \varepsilon, \tag{4}$$

where y^* is the dependent variable, ***x*** is the vector of independent variables, and β is the vector of regression coefficients which we wish to estimate. We only observe *Y*, which is the optimal level of efficiency or number of DAMs that maximizes the grower's unobserved utility. We observe:

$$y = \begin{cases} 0 \; if \; y^* \leq 0, \\ 1 \; if \; 0 < y^* \leq \mu_1, \\ 2 \; if \; \mu_1 < y^* \leq \mu_2, \\ \quad . \\ \quad . \\ N \; if \; \mu_{N-1} < y^*. \end{cases} \tag{5}$$

where *N* is the maximum level of efficiency or number of DAMs.

To estimate the number of DAMs adopted we also use an ordered probit model. Ideally, we would use a multinomial logit model to estimate the grower's choice of DAM bundle, but due to small sample size, such estimation is not possible.

5.2.4 Seemingly Unrelated (SUR) Bivariate Probit

In addition to estimating the probability of adopting sensor technology with a probit model, and the number of DAMs adopted, and the choice for an irrigation system of a certain efficiency with an ordered probit, we estimate the probability of adopting at least one measure from each of two categories of DAMs. Since the error terms are likely correlated across these two probabilities, we utilize an SUR bivariate probit model. This model allows for the independent influence of the independent variables on each DAM but allows the error terms to be freely correlated (Lin *et al*., 2005). We estimate equation (2) for categories *i* and *j* and allow ε_i to be correlated with ε_j. We utilize Stata's biprobit procedure which estimates two-equation probit models, by the method of simulated maximum likelihood (SML).

5.3 Explanatory Variables

The variables included in our model are shown in Figure 5-1. The figure is not intended to show how the independent variables affect each other or how adoption affects the independent variables. Table 5-8 shows the descriptive statistics for the explanatory variables of the sample of farmers in Florida.

5.3.1 Dependent Variables

In this study we investigated which factors are correlated with four dependent variables related to adoption of DAMs. Since we had several measures and explanatory variables, but a limited number of observations, we had to be creative in our data analysis. In this study we looked at the following four dependent variables:

1. Choice for the irrigation efficiency: The main focus of this study was on adoption of efficient irrigation. We modelled the choice for an irrigation system of a certain efficiency with an ordered probit model. The irrigation systems and the frequency with which the growers in our sample use them are shown in Table 5-4.
2. Adoption of two groups of adaptation measures: Modelling adoption of each DAM through separate probit analyses would have been too cumbersome and might have missed important correlations between adoption of different groups of DAMs. We therefore used a bivariate probit to model the decision to adopt one or more apply augmentation measures or measures to reduce non-productive losses.

3. The number of measures adopted: we used an ordered probit to investigate the factors that determine the intensity of adoption of DAMs.[4]

4. Adoption of sensor technology: Because of the previously described ways of modelling adoption, we were not able to include variables related to the perceived attributes of the innovation. We wanted to show the importance of these variables, and therefore we modelled adoption of sensor technology with a separate probit model. Sensor technology was chosen because it was not included in the bivariate probit analysis.

Table 5-5 gives the summary statistics for our outcome variables, and for some of the measures contained in the outcome variables.

5.3.2 Explanatory Variables

This section describes the factors or attributes which were included in our model as regressors. Some factors relate to a representative acre of farmland. The variables are summarized in Table 5-8.

5.3.2.1 Grower or demographic characteristics

As chapter 4 described, gender is often included as a variable in models that attempt to explain adoption (Prokopy *et al.*, 2008). We included the variable *Gender* in our model to see if it is a significant determinant of DAM adoption in Florida. It is a dummy variable that takes the value 1 for female.

The variable *Age* measures the age in years of the farm manager. The survey asked for the year of birth rather than the farmer's age because it was assumed to be a less intrusive question. We hypothesized that age has a negative influence on adoption levels. Age and adoption might also exhibit a quadratic relationship, as both

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[4] There were 14 DAMs that could potentially be adopted: irrigation, lining of canals or reservoirs, soil improvement measures/mulching, land leveling, alternative freeze protection, sensors, weather station, variable rate irrigation, automatic irrigation, rainwater harvesting, use of reclaimed water, tailwater recovery, and agricultural drainage. The latter was not included for the study in Florida.

young, less financially established farmers and older farmers might be less likely to adopt. The model therefore also included a quadratic transformation of age: *AgeSq*.

We hypothesize that more experience means a higher likelihood of adopting adaptation measures. However, as with age, this could also be a quadratic relationship.

We assume a positive relationship between education level and adoption, since some DAMs can be technically challenging, and education level is assumed to be a proxy for the ability to implement technically difficult measures. In the regression model we used a dummy for having college and/or postgraduate experience: CollegePhD.

5.3.2.1 Farm characteristics

The survey measured farm size, as acres of land owned, leased or otherwise obtained, and sales with ten categories of gross annual sales. The percentages of growers for each sales category are presented in Table 5-6. These responses are represented by Acres and two dummies for sales, respectively. The first dummy is Plus250 and takes the value 1 for sales over US$ 250,000 per year. This is the threshold that USDA uses to distinguish between small and large farms. The variable Minus50 takes the value 1 for sale levels under US$50,000. A higher level of sales implies the ability to invest in technologies and to bear the risk associated with its adoption. A positive relationship should be expected between Plus250 and adoption level, and a negative relationship between Minus50 and adoption level. We did not look at access to credit. Nine growers indicated they are not commercial farmers. We grouped them with the sales class of up to $10,000. This led to a total of seventeen respondents for that category.

We also include a variable for tenure (Tenure), which is the percentage of land owned. The common hypothesis is that farmers are more willing to make long-term investments tied to land if they have a more secure claim to this land, for example through ownership rather than a (short-term) lease. However, the adoption literature shows positive, negative, and insignificant correlations. Prokopy *et al.* (2008) only identified one study of water management related BMP adoption where tenure had a significant correlation with adoption; and in this study the correlation was negative. Knowler and Bradshaw (2007) identified 13 analyses that investigated the effect of land tenure on conservation agriculture adoption, and also found mixed results, with two studies showing a positive correlation, two a negative, and nine studies not finding any significant correlation. We think the positive effect will mainly occur for measures such as long-term investments that are tied to the land. However, this is only the case for a few DAMs. Still, we follow the general hypothesis and hypothesize that land ownership is positively related to adoption of DAMs. We measured this variable in continuous form, as the percentage of the acreage that is owned.

Crop type was included in the model by botanically grouping the crops. We do not have a hypothesis related to the botanic crop group that a grower grows but we do think that there could be an influence, since some DAMs are better suited for some crops (e.g. drip irrigation is more suitable for strawberry production than for grasses or grain crops). Moreover, some crops have a lower drought tolerance than others. For example, summer squash, radish, and spinach have low drought tolerance. Unfortunately there is a lot of variation in irrigation needs within our botanical crop groups. We also believe that growers might invest more in DAMs if they grow high-value crops. Therefore, additional research could be done where the crops are classified based on drought tolerance and economic value per unit. The crop families and the percentages of growers in our sample growing these crops, are shown in Table 5-7. Due to a small sample size, not all crop family dummy variables could be included, so those for which the effect is hypothesized to be greatest were included with the remaining crop families serving as an aggregate base.

5.3.2.3 Risk perceptions and preferences

We hypothesize that the grower's perception of the drought problem will influence the decision to adopt DAMs. Here we made a slight change to our definition of drought because we are not necessarily interested in the grower's opinion on changes in meteorological drought, but more in how the grower expects the on-farm water availability will change, which can also be caused by increased water demand.

Drought risk is the combination of the probability of drought and its consequences. Perceptions of this risk vary across growers. We measured drought risk perception through a dummy variable. The variable WaterAvOP is a dummy, which takes the value 1 if the grower expects water availability to often be problematic in the future. The variable Canunpr is a dummy which takes the value 1 if the grower indicates that the water supply is sometimes or often unpredictable. The variable OftUnpr takes the value 1 if the grower indicates that he or she considers the water supply to be often unpredictable.

We anticipate that farmers who are more risk averse will be more likely to adopt measures to reduce the risk of drought damage. On the other hand, new practices are risky themselves, so there could also be a negative effect of risk aversion on adoption levels.

We measured risk preference as the number of crops grown, CropDiv, which is a proxy for crop diversity as a risk spreading practice. The survey also asked growers about their crop insurance. For insurance we have both a yes/no dummy called Insurance, and another dummy called IntInsur that takes the value 1 if the grower has insurance or would like it but does not qualify. Some growers may be risk averse and want insurance but not be able to get insurance. In our sample, 39 percent of the growers has insurance. The same percentage does not have insurance and is not interested in it. However, 22 percent want insurance but their operation does not qualify.

5.3.2.4 Environmental and spatial characteristics

The survey included several environmental and spatial variables. It asked growers about the surface and subsurface soil types on their operation, where they could choose from several categories. For our analysis we constructed two dummy variables: one for soils with high water retention capacity, and one for low water retention capacity. The high water retention dummy takes the value 1 if a grower's soil either has a mineral fine texture including clay and clay loam soils, or is a soil that is rich in organic matter (peat or muck). Some growers ship in artificial soil. They were grouped under the high retention capacity soils. The low water retention dummy takes the value 1 if the grower's soil has a mineral coarse texture, including coarse sand, gravel and rockland. Coarse, sandy soils generally transmit water quickly and do not retain water well. Some growers have a soil that falls outside of these two groups, and they are used as the base group. They include growers with sandy clay, fine sand and loam soils.[5]

The growers we contacted through the FDACS list were not asked about their soil type. We used ArcGIS to geocode these growers on a soil map, thus obtaining information on their dominant soil type.

[5] Permeability refers to the capacity of the soil to transmit water.

Another spatial variable was the proximity of a surface water body. The survey asked growers about the distance to the nearest surface water body. To determine the distance to the nearest water body for the list of addresses we received from FDACS, we also used geocoding in ArcGIS. We used a data layer, which showed all water features in the state of Florida. Glaciers, marshes, oceans and streams referred to as “dry” were removed. Then we used shapefiles at the WMD level from the Florida Geographic Data Library showing the main land use, which also included agriculture and water. We merged the five WMD shapefiles into one file, selected the water bodies, exported only the water body data, and combined this with the data layer of the major water bodies in Florida. Then we calculated the distance from the respondent’s agricultural parcel, identified on an agricultural parcels data layer, to the nearest water body. When the grower’s parcel was ambiguous, we did not enter a value. The other respondents were asked about the distance between the nearest water body and the closest border of their cultivated land. There is a risk of type one error, i.e. stating there is a water body nearer than there really is. However, for the addresses that were geocoded there was more uncertainty about the distance, as some agricultural parcels were not clearly identified on the map, and some addresses were post office boxes. Therefore we switched to dummies: one for proximity of a surface water body (within 500 feet of the nearest border) and zero otherwise. For the geocoded addresses where we were not sure about the location of the farm we entered missing values.

A third spatial factor we included was the NeigborPos variable, a dummy which takes the value one if the grower perceives his/her neighbor to have a positive attitude towards DAMs. The survey asked the respondent whether his/her neighbors are positive, negative or neutral with respect to DAMs. This was the only question in the survey with a ‘don’t know’ option, which was selected by 48 percent of the respondents. The majority of the other respondents, i.e. 30 percent, indicated that their neighbors are positive about DAMs. There were 9 percent who thought their neighbors were negative about it, and 12 percent indicated a neutral perceived attitude.

We hypothesize that if the neighbors are positive about DAMs, then the respondent is more likely to also be positive about this, and vice versa for the other dummy. Of course in the age of internet ‘information neighbors’ are not necessarily geographical neighbors. Still, we think the opinion of neighbors can be influential.

A final spatial variable we included measured if a grower had experienced water shortage in the past. The question had several answer categories, ranging from not having experienced any water shortage, to water shortage without any damage, with moderate damage, or with substantial damage. The majority of the respondents indicated they have not experienced any water shortage in the past ten years (61 percent). Twenty percent of the growers had experienced substantial damage due to water shortage.

Although drought adaptation can be both proactive and reactive, we expect growers that have experienced drought firsthand to be more inclined to adopt DAMs. We used a dummy variable for having experienced any water shortage, AnyShort, and a dummy for having experienced water shortage with damage, ShortDam.

This is related to the variable Cutback, which represents whether or not a grower has been asked to cutback water use. Areas in which growers are asked to cutback water use are normally areas where drought is a problem.

In this study we also wanted to include spatial econometric analysis. However, due to data limitations this could not be completed as planned. Additionally, with the low response rate, respondents are likely spread far enough apart that spatial correlation is not present. We did, however, include the spatial characteristics of soil type and the presence of a stream to account for spatial differences. We also asked about the attitude of neighbors towards DAMs for the contagion effect.

5.3.2.5 Institutional variables

We hypothesize that growers are more likely to adopt DAMs if they are enrolled in a cost-share program such as EQIP. COSTSHARE is a dummy variable, which measures whether or not the farmer received project assistance such as government subsidies for the DAM investments (1 if yes, 0 if no). The dummy variable is expected to have a positive influence on adoption of DAMs. We included a second dummy for having used MIL services. In our sample 46 percent has made use of this service, 28 percent has not but would be interested in using it, and 27 percent has not made use of it and is not interested in it.

Fuglie (1999) used a multinomial logit model to assess the effects of cost-share programs on the adoption of conservation tillage and the effects of adoption on yield and input use. Results indicated that those farmers in cost-share programs as well as farmers with greater erosion problems were more likely to adopt conservation tillage (Fuglie, 1999). This indicates that the programs have been effective.

5.3.2.6 Perceived attributes of measures

For four measures that are crop specific, we asked growers if it would be technically possible to implement the measures and then asked the growers about their perceived attributes of the measures. If a grower indicated it was not technically possible to implement a certain DAM he was not asked the follow-up question. Therefore a negative response to the technical possibility question is a perfect predictor of non-adoption.

The perceived attributes of the innovation have been said to be important factors influencing adoption. However, we did not specifically ask growers how they think the measures reduce their vulnerability to drought, which is one of the limitations of our study. We did ask the growers to indicate what they think about the difficulty and costs of the DAM, as well as its effect on yields and labor requirements. We used this for one of our models, which explains adoption of sensor technology. Feather and Amacher (1994) showed that profit perceptions have a larger effect on adoption rates of BMPs than environmental perceptions. We therefore also included the perceived costs and effect on yields of adopting sensors.

We also asked non-adopters of drip irrigation for the reasons why they do not use it. These barriers are thus perfect predictors, and are therefore not included in the model. The barriers to adoption were based on the Farm and Ranch Irrigation Survey (FRIS).[6] The survey asked growers who had recently converted to more efficient irrigation systems if this enabled them to expand their acreage or change their crop plan, and if their total water extractions have changed. Because of the low number of observations in this category, we only use descriptive statistics to describe the data in terms of the 'rebound effect'.

5.4 Sample Representativeness

To find out if our sample is representative of field vegetable growers in Florida, we compared the sample values to the population values (according to the 2007 census of agriculture) in terms of age, gender, and sales.

In 2007 the average Florida farmer was 58.4 years of age. The average U.S. vegetable and melon grower had an average age of 55.9 years. Our sample average age is 52.6. Therefore, although we do not know the current average age for

[6] This is a survey that is done every five years, devoted entirely to collecting on-farm irrigation data for the United States.

vegetable growers in Florida, our sample might have a lower age than the population we want to make inferences about. Younger growers might be more concerned about future water availability since they will be farming farther into the future than older growers. Thus, our survey may have appealed to younger growers, and we may overestimate the likelihood of adoption of DAMs.

The USDA defines a small farm as one having gross sales less than $250,000 (Hoppe, MacDonald and Korb, 2010). According to the 2007 Census of Agriculture, 93 percent of farms in Florida fall into this category. In our sample, for the growers who answered this question, 52 percent manage small farms. Therefore, our sample contains relatively more large farms than the actual population. As previous literature has shown, managers of large farms are more likely to utilize irrigation and adopt new technology (Maddison, 2007; Prokopy *et al.*, 2008). Consequently, our survey may have attracted these kinds of growers.

In the U.S. in 2007 16.7 percent of all vegetable growers were female. In Florida 22 percent of all farmers are female. In our sample 19 percent of the respondents are female. This is relatively close to the percentage of female growers in our research population, so our respondents are representative of the actual population in terms of gender (USDA NASS, 2007).

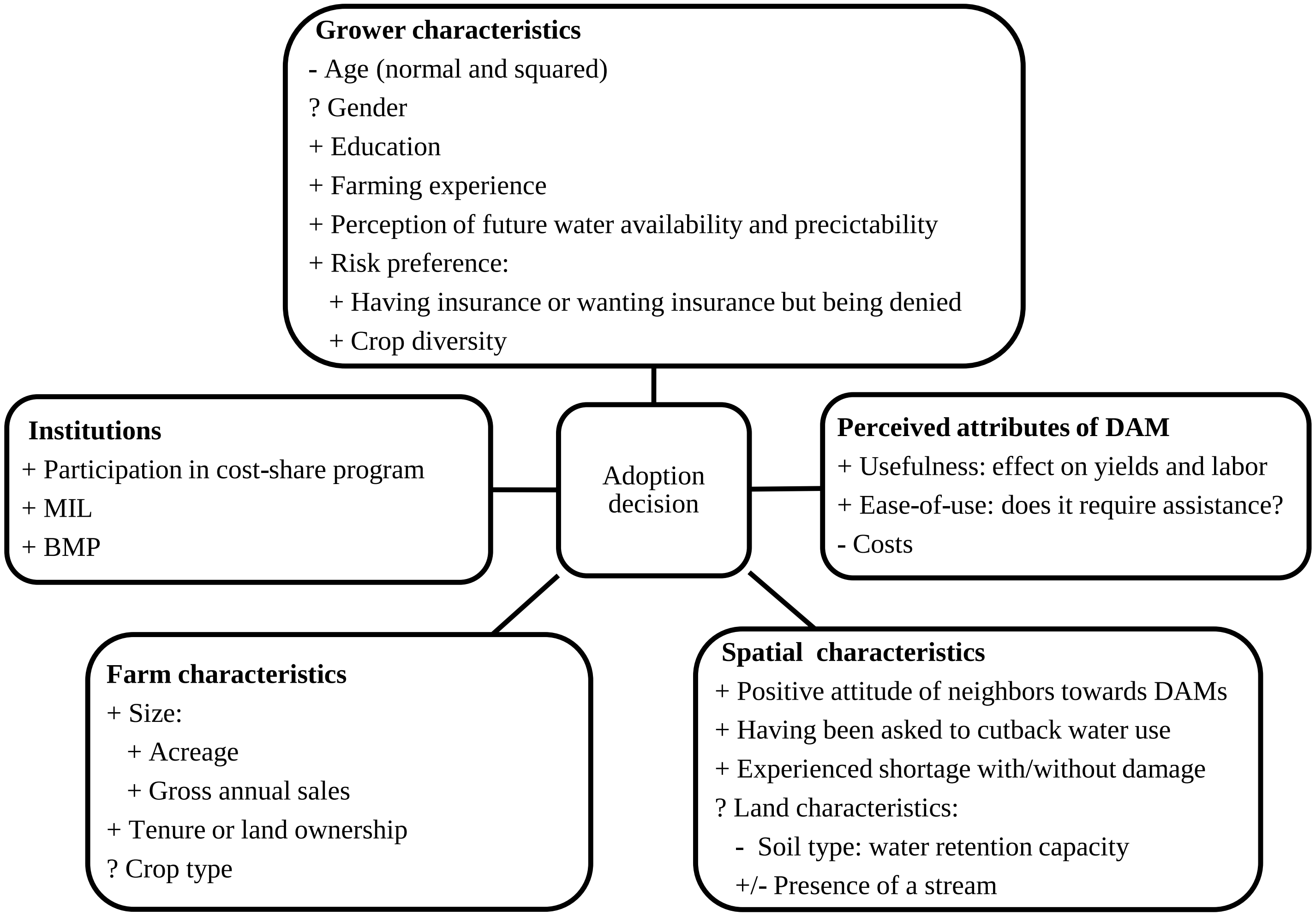

Figure 5-1. Variables included in our model (bullet symbols reflect expected signs with “?” indicating conflicting expectations based on the literature).

Table 5-1. Distribution of the survey among people on the FDACS list.

Date	Number of responses	% of responses	Comments
23 April 2013	8	11.3	I assume the next mailing arrived on the second of May, so I include everything until and including May 1st
30 April 2013	28	39.4	I assume the third mailing arrived in the 14th of May, so everything between May 2nd and 13th
13 May 2013	25	35.2	I assume the fourth mailing arrived on the 28th of May, so everything between May 14 and 27.
27 May 2013	10	14.1	Everything after May 28.
TOTAL	71	100	

Table 5-2. Response rates for the different channels of distribution in Florida.

County	People invited (wrong addresses not included)	People who started the survey	Usable responses	Refused to participate	Medium	Response rate: returned		Response rate: usable	
Bay county	5	2	1		Farmers market + e-mail	40.00	%	20.00	%
Duval county	2	1	0		E-mail	50.00	%	0.00	%
Manatee county	224	7	4		E-mail	3.13	%	1.79	%
Martin county	3	3	2		E-mail	100.00	%	66.67	%
Miami-Dade county	30	4	4		E-mail	13.33	%	13.33	%
Okaloosa county	9	5	5		E-mail	55.56	%	55.56	%
Okeechobee county	22	0	0		E-mail	0.00	%	0.00	%
Santa Rosa county	12	3	3		E-mail	25.00	%	25.00	%
St. Lucie county	2	1	0		E-mail	50.00	%	0.00	%
Seminole county	83	7	0		E-mail	8.43	%	0.00	%
Volusia county	83	4	1	1	E-mail	4.82	%	1.20	%
Walton county	12	2	1		E-mail	16.67	%	8.33	%
Charlotte, Collier, Glades, Hendry, Bradford, Palm Beach and Levy County[1]	251	63	35		E-mail	25.10	%	13.94	%
SUB TOTAL	738	102	56	1		13.82	%	7.59	%
FDACS	509	72	63		4 letters	14.15	%	12.38	%
Florida Farm Bureau	255	58	46	4	E-mail	22.75	%	18.04	%
TOTAL	1,502	232	165	5		15.45	%	10.99	%

[1] The calculation for this response rate does not include any newsletters in which the URL may have been included. This category also includes one of the growers who pre-tested the survey and after whom no more changes were made to the survey.

Table 5-3. Response rates for the different channels of survey distribution in Limburg.

Channel	People invited	People who started	Usable responses	Medium	Response rate: returned	Response rate: usable
LLTB/ websites	1,217	24	5	Newsletter/ websites	1.97 %	0.41 %
Letter	369	17	11	1 letter	4.61 %	2.98 %
TOTAL	1,586	41	16		2.59 %	1.01 %

Table 5-4. Choice of irrigation efficiency.

Variable	Number of observations in dataset
No irrigation	18
Flood or seepage irrigation	26
Sprinkler or overhead irrigation	55
Micro-irrigation	63
TOTAL	162

Table 5-5. Summary statistics of dependent variables.

Variable	Number of observations	Mean	Standard Deviation	Minimum	Maximum
Tailwater recovery	156	0.17	0.37	0	1
Rainwater harvesting	156	0.16	0.37	0	1
Desalinated water use	156	0.01	0.11	0	1
Reclaimed water use	156	0.01	0.08	0	1
Irrigation	162	0.89	0.32	0	1
Sensors	140	0.26	0.44	0	1
Automatic irrigation	138	0.44	0.50	0	1
Weather station	139	0.34	0.47	0	1
Variable rate irrigation	140	0.56	0.50	0	1
Lining	152	0.02	0.14	0	1
Mulching	152	0.22	0.42	0	1
Leveling	151	0.23	0.42	0	1
Alternative freeze protection	150	0.18	0.39	0	1
Number of measures adopted	165	3.15	2.05	0	10
Measures to reduce NPL	151	0.40	0.49	0	1
Irrigation planning measures	143	0.80	0.40	0	1
Supply augmentation	155	0.30	0.46	0	1
Irrigation efficiency	162	2.17	1.00	0	3

Table 5-6. Number of observations per category of gross annual sales.

Category	Observations	Percentage	Cumulative
1= < 9,999 (and non-commercial)	17	14.53	14.53
2= 10,000 – 24,999	5	4.27	18.8
3= 25,000 – 49,999	16	13.68	32.48
4= 50,000 – 99,999	12	10.26	42.74
5= 100,000 – 249,000	12	10.26	52.99
6= 250,000 – 499,999	5	4.27	57.26
7= 500,000 – 999,999	34	29.06	86.32
8= >1,000,000	16	13.68	100
TOTAL	117	100	

Table 5-7. The percentages of respondents in Florida that produce certain crops.

Crop Name/Family	% of respondents	% of respondents	Crop Name/Family	% of respondents	% of respondents
Berries		18.1	Malvaceae Family		15.1
Blackberry	1.2		Cotton	1.8	
Blueberry	3.6		Okra	13.3	
Lychee	0.6		Nightshade Family		39.8
Muscadine grape	1.8		Eggplant	18.7	
Strawberry	12.7		Bell pepper	25.9	
Cabbage Family		24.7	Hot pepper	18.1	
Broccoli	10.2		Potato	15.1	
Cabbage	16.9		Tobacco	0.6	
Cauliflower	5.4		Tomato	30.1	
Collard greens	2.4		Onion Family		16.9
Kale	12.0		Garlic	0.6	
Radish	13.3		Leek	1.8	
Watercress	1.2		Onion	16.9	
Turnip	10.8		Shallot	0.0	
Carrot family		15.7	Ornamental Plants/cut flowers/trees		17.5
Carrot	15.1		Cut- and wildflowers	1.8	
Celery	2.4		Herbs	3.0	
Cucurbit Family		30.7	Ornamental plants	10.8	
Cantaloupe	10.8		Ornamental trees	3.0	
Cucumber	1.8		Other tree crops		8.4
Pumpkin	7.2		Avocado	1.2	
Squash	17.5		Banana	0.6	
Water- or bitter melon	16.9		Citrus	4.2	
Goosefoot Family		12.0	Peach	1.8	
Beet	0.6		Other leafy greens		18.1
Chard	1.2		Lettuce	15.7	
Spinach	11.4		Endive	1.8	
Grasses/Grains Family		35.5	Pea/Bean Family		33.1
Field corn	4.2		Peanuts	7.8	
Hay	7.2		Peas	14.5	
Oats	0.6		Snap, string or green Beans	21.7	
Rice	1.2				
Ryegrass	0.6				
Sorghum/milo	1.2				
Soybeans	0.6				
Sugar cane	7.8				
Sweet corn	17.5				
Turfgrass/sod	2.4				
Wheat	0.6				

Table 5-8. Summary statistics of explanatory variables.

Category	Variable abbreviation	Description	Number of observations	Mean	Standard Deviation	Minimum	Maximum
Grower	Age	Farm manager's age in years, calculated with birth year data.	117	52.6	11.7	22	79
	Gender	Gender of the farm manager. Dummy: 1 if female, 0 if male.	134	0.2	0.4	0	1
	CollegePhD	Dummy: 1 if college degree or postgraduate school, 0 if not.	133	0.6	0.5	0	1
	Experience	Years of farming experience on this or a similar operation.	115	19.4	13	1	55
	WatAvOP	Dummy: 1 if perceived future water availability is often problematic; 0 if not.	146	0.1	0.3	0	1
	CanUnpr	Dummy: 1 if water supply is sometimes or often unpredictable; 0 if not.	147	0.3	0.5	0	1
	OftUnpr	Dummy: 1 if water supply is often unpredictable; 0 if not.	147	0.1	0.3	0	1
	Insurance	Dummy: 1 if yes; 0 if not.	126	0.4	0.5	0	1
	Intinsur	Dummy: 1 if yes or denied; 0 if not interested.	126	0.6	0.5	0	1
Farm	CropDiv	Number of crops grown in a typical growing season.	165	4.7	5.6	0	23
	Acres	Acreage under production in a typical growing season	159	1087	3041.9	0	27,800
	Plus250	Dummy for sales: 1 if > $250,000; 0 if not.	117	0.5	0.5	0	1
	Minus50	Dummy for sales: 1 if < $50,000; 0 if not.	117	0.3	0.5	0	1
	Tenure	Percentage of the farmland owned by the farmer.	157	0.7	0.3	0	1
Location and contagion	Sandy	Dummy: 1 if sandy, coarse soil; 0 if not.	158	0.2	0.4	0	1
	PeatClay	Dummy: 1 if muck, peat or clay soil; 0 if not.	158	0.3	0.4	0	1
	Stream	Dummy: 1 if surface water body within 500 feet; 0 if not.	134	0.4	0.5	0	1
	Neigbpos	Dummy: 1 if neighbor positive; 0 if not.	143	0.3	0.5	0	1
	Cutback	Dummy: 1 if ever asked to cutback water-use; 0 if not.	144	0.3	0.5	0	1
	ShortDam	Dummy: 1 if experienced water shortage with damage in past 10 years; 0 if not.	148	0.3	0.4	0	1
	AnyShort	Dummy: 1 if experienced water shortage in past 10 years, with/without damage; 0 if not.	148	0.4	0.5	0	1
Institutions	MILyn	Dummy: 1 if used MIL; 0 if not.	144	0.3	0.4	0	1
	BMP	Dummy: 1 if enrolled in the BMP-program; 0 if not.	145	0.1	0.3	0	1
	Costshare	Dummy: 1 if enrolled in a cost-share program; 0 if not.	147	0.3	0.4	0	1

CHAPTER 6
RESULTS AND DISCUSSION

This section of the study documents the analysis of the responses from the survey, in order to identify characteristics that influence the adoption of drought adaptation measures. The regression output tables can be found in Appendix B.

Section 6.1 first outlines the results of the ordered probit regression for choice of irrigation efficiency. We combine this with a description of the barriers that non-adopters identified, and a brief description of the variables related to the rebound effect, or Jevons' paradox. Section 6.2 discusses the results of a bivariate probit model which aims to explain adoption of supply augmentation measures and measures that reduce water losses. Section 6.3 follows with an analysis of the results of the ordered probit regression that looked at intensity of adoption, measured as the number of DAMs adopted. Section 6.4 describes the last analysis we did, which is a separate probit for adoption of sensor technology. Section 6.5 ends the chapter with a description of the results for Limburg, for which we unfortunately did not have enough responses to estimate the models.

6.1 Factors Influencing Adoption of Efficient Irrigation

Our survey asked growers which percentages of their acreage are irrigated with seepage/flood irrigation, overhead irrigation, and micro-irrigation. If they did not use any supplemental irrigation on all or a part of their acreage they could either enter zeros or specify this under 'other'.

Some growers used more than one irrigation system. Most of these growers indicated that they used a certain type of irrigation on 90 percent or more of their land, and we decided to classify them under their main irrigation system used. However, there were 10 growers who used two or three types of irrigation system on (almost) equal shares of the total acreage (with a difference of less than 20 percent).

However, for our ordered probit we could only put each grower in one irrigation category. With more data we could have used a multinomial logit model for the choice of irrigation system, including possible combinations of systems. Instead, we classified each grower according to the irrigation system used on either more than 90 percent of their acreage, or, if there was not one such irrigation system, we classified them under the most efficient system they used.

As shown in Table B-1, which presents the results from our ordered probit model estimation, there were several variables that had a significant relationship with adoption of more efficient irrigation. It is important to note that growers who indicated they do not use any irrigation were not included in this model, as they cannot be classified as 'inefficient' or 'efficient.' This left us with 95 observations.

6.1.1 Discussion of Model Results

The model contains three variables that measure risk perceptions and risk aversion: the perception of unpredictable water supply, having or being interested in crop insurance, and crop diversity. We hypothesized that growers who perceive greater risk and/or who are already engaged in risk insurance activities would be more likely to adopt a more efficient irrigation system. The results largely support this hypothesis. There is a positive correlation between a water supply that is perceived as unpredictable and adoption of more efficient irrigation, and crop diversity if positively correlated with efficiency level adopted. However, there is not a significant relationship between insurance and efficiency level, but the coefficient's sign is positive, as hypothesized.

Another interesting finding is that being an operator of a small farm (i.e. with gross sales of less than $50,000 per year) increased the probability of adapting efficient irrigation. This is important information for policymakers; 'small farms' are adapting to drought and do not seem to be inhibited by financial limitations. Also, the larger the share of the cultivated land that is owned by the grower, the higher the probability that he or she uses more efficient irrigation. This may be because it is an investment that is tied to land. Growers may be more willing to make this investment if they have a relatively secure claim to the land. This result fits the hypothesis of the Economic Constraint Model (Feder *et al.*, 1985), and the findings of Hassan and Nhemachena (2007) and Schuck *et al.* (2005).

Our results also indicate that adoption of more efficient irrigation depends on crop type. There is a higher probability of adoption among growers who cultivate berries and lettuce and endives (other leafy greens). These are relatively high-value crops, which can lose value quickly if they do not get sufficient irrigation. This outcome therefore supports our hypotheses.

Adoption is negatively influenced by growing cabbage or goosefoot. This makes sense, as cabbage is generally irrigated with seepage in Florida in areas with a high water table. These areas might also be less prone to drought damage because of higher water levels. Goosefoot includes beet, chard and spinach, and in our sample spinach is the largest component of this variable. Spinach can be irrigated with drip, but thrives better when its leaves get wet.

Spatial variables were also shown to be significant. Both coarse sandy soils and clay and peat soils positively influence adoption of more efficient irrigation. We have mentioned why this was to be expected for sandy soils (see also Shrestha and Gopalakrishnan, 1993). For clay and peat soils, however, it could be the case that more high-value crops are grown on these types of soils, which we expect to be more likely to be irrigated with more efficient drip irrigation.

Finally, having been asked to cutback water use, as well as having experienced shortage with damage have a significant negative correlation with adoption. It could be that growers experience damage because they have not adopted. Support programs that stimulate converting to more efficient irrigation do not show a correlation with adoption in our sample, suggesting that perhaps they are not targeting the proper audience or not providing enough support to stimulate adoption. The surprising signs on these variables could also be due to multicollinearity between these two variables and between these two variables and the grower's perceptions of drought.

6.1.2 Barriers to Adoption

Growers who do not use micro-irrigation were asked to indicate why they do not use it, from a list of possible barriers provided by FRIS. Table 6-1 shows the main reasons why the non-adopters in our sample did not adopt it. For the majority, micro-irrigation does not match their crop or field conditions. For another large share, the improvement is not seen to lead to sufficient improvements to cover the costs. Additionally, many respondents indicated that they will not be farming long enough to make these investments, which fits the data on Florida's rapidly aging farmer population.

Policymakers may be interested to hear that 18 percent of the non-adopters do not adopt because they cannot finance the installation costs. This means support programs could influence adoption behavior, although more research is needed on what kind of farmers these are, and how this coincides with or differs from the targeting by the existing cost-share programs. A number of growers indicated they do not use micro-irrigation because they are worried that their water use permit may be revised downward.

6.1.3 Jevons' Paradox

In our sample, 80 of the 166 growers indicated that they use micro-irrigation. We asked these growers if they have always used micro-irrigation, or if they had recently converted to using micro-irrigation. The growers who had converted (N=51), were asked how this change has affected their yields, total acreage cultivated, and total amount of water extracted, since these are three ways in which consumptive water use can increase.

If Jevons paradox holds true for efficient irrigation systems in Florida, we would expect the growers to have either increased their acreage (if water was that much of a limiting factor, which we do not expect it to be), their yields, or the amount of water extracted (pumped or otherwise obtained). Table 6-2 below shows what the growers indicated were the effects of converting to micro-irrigation. From these answers we can learn that micro-irrigation has the positive effect of increasing yields, and reducing water extracted. However, if yields increase, consumptive water can increase as well. Moreover, several farmers expanded their acreage after converting to micro-irrigation. Growers were also asked to indicate if they agreed with the statement "micro-irrigation allows me to expand my acreage." This could be leading people on, but might still provide insights. There were 21 growers who indicated that this statement applied to them. Therefore, Jevons paradox could exist in Florida for some growers.

6.2 Factors Influencing Adoption of SA and NPL Measures

We used a bivariate probit model to investigate the factors influencing adoption of supply augmentation (SA) measures and measures to reduce non-productive water losses (NPL). We also test the null hypothesis of no correlation between the error terms across the equations.

6.2.1 Description of the Data

Of the 153 respondents who answered the question, 51 indicated that they use some type of water supply augmentation measure. As can be seen in Table 6-3, some of these growers used several of these measures; mostly combining tailwater recovery and rainwater harvesting. 109 growers indicated that they do not apply any of these supply-augmenting methods.

For the adoption of measures to reduce water losses, the respondents were first asked if it was technically possible to implement lining, mulching, leveling and alternative freeze protection. We did this because it does not make sense to ask someone about the aspects of lining a reservoir if he or she does not have a reservoir. This gave us different numbers of observations for each measure. These, and the number of growers using a certain measure, are shown in Table 6-4. A total of 149 growers answered the appropriate questions in this section of the survey for their particular operation.

6.2.2 Outcome of the Model

Table B-2 shows the results of the bivariate probit model estimating the probability that a grower adopts supply augmentation measures and measures to reduce non-productive water losses. Our model shows that adoption of measures to reduce nonproductive water losses is positively related to being female, which we hypothesized because women may be more concerned about their environment (Newmark *et al*., 1993: Burton *et al*., 1999; Dolisca *et al*., 2006). These measures are, with a possible exception for the rebound effect, good for the environment. For example, tailwater recovery reduces agricultural runoff and thus reduces the amount of pollutants discharged into the environment.

There is also a significant and positive correlation between adoption of measures to reduce nonproductive losses and having a college degree and/or postgraduate education. As in other studies, we hypothesized that education positively influences adoption of innovations, as it increases a person's ability to receive, decode and use information (Schultz, 1975). Our results also show that adoption is positively related to having or being interested in insurance, and to growing a large number of crops.

We hypothesized that both a preference for insurance and cultivating a larger number of crops are measures of a person's risk aversion. Risk averse people are hypothesized to be more likely to adopt these DAMs. Growing berries also increases the probability of adoption, which may be because they are relatively high-value crops.

Moreover, one spatial effect is shown to have a significant relationship with adoption. Growers who indicated that their neighbors have a positive attitude towards DAM were more likely to adopt DAMS themselves. This indicates that spatial contagion might play a role, as we hypothesized it might.

Adoption of supply augmentation measures is influenced by different variables. In accordance with a large number of adoption studies and our hypothesis, acreage positively influences adoption. We expected this outcome for supply augmentation measures in particular, as some of them require a large surface area, e.g. to build a reservoir. There is a very strong and significant negative result for tree crops. The main supply augmentation measures are tailwater recovery and rainwater harvesting, and the main tree crop is citrus. However, for tailwater recovery you need to have flood or furrow irrigation, and citrus in Florida is mainly irrigated with micro-irrigation. Moreover, citrus is a relatively drought-tolerant type of tree, and cannot tolerate saturated soils.

There are also two spatial variables that influence adoption of supply augmentation measures. Peat and clay soils show a positive relationship with adoption. We were expecting the opposite, since clay and peat soils have a higher water retention capacity than coarse sandy soils. On the other hand, as was hypothesized in the model for irrigation efficiency, higher-value crops may be cultivated on clay and peat soils, which may enable more investments in supply augmentation measures.

The null hypothesis of no correlation across errors terms in the two equations was rejected.

6.3 Factors Influencing the Intensity of Adoption

We used an ordered probit model, the results of which are shown in Table B-3, to investigate the factors that influence the intensity of adoption, which we measured as the number of DAMs adopted. There were several variables which showed a significant relationship with adoption.

Several of these variables were related to grower characteristics. We used the median value of experience to replace the missing values for this variable. Still, despite the fact that this reduces variance, its coefficient is still statistically significant and positive, demonstrating that the effect is a robust result. As the previous section described, we hypothesized that a preference for insurance would increase the intensity of DAM adoption, and this was shown to be the case.

Perceived future water availability has a statistically significant negative coefficient. This is not in line with our hypothesis, which we based on Protection Motivation Theory, that adoption of adaptation measures is (positively) influenced by the grower’s perception of the adverse outcome (Rogers, 1983). We suspect that this variable is not only picking up the grower’s perceptions about water supply risk but also possibly their attitudes in general about risk. These growers may be risk averse when it comes to investing in and adopting new technology, reducing their intensity of adoption.

Farms with larger sales (over $500,000 per year) have a positive relationship with adoption. We, and many other previous studies, hypothesized that having higher sales means a grower has more capital to invest. Growing berries again shows a positive significant effect, which is, as described above, what we hypothesized. Growing crops from the Potato/Nightshade family also exhibits a positive relationship with adoption. The main crops in this category are tomato, hot/bell peper and eggplant. These are relatively high-value crops, which may explain the positive relationship with adoption intensity.

The Goosefoot crop family again has a negative relationship with adoption. Apparently spinach, beet and chard are not crops that incentivize the adoption of DAMs. The last significant and positive effect comes from having been asked to cutback water use. We hypothesized that having been asked to cutback water use makes growers increasingly realize the scarcity of water, thus increasing its perceived shadow price. The results suggest that this is the case. Dissemination of information regarding water shortages may encourage adaptation.

6.4 Factors Influencing Adoption of Sensor Technology

These three models have ignored one important set of possible predictors of adoption: the perceived attributes of the measure. We therefore modeled adoption of sensor technology, which is a relatively high-tech costly measure in comparison to some of the other measures. It has also been shown to have high potential for increasing yields. The results of our model, shown in Table B-4, show that these perceived attributes are very significant explanatory variables. Believing that sensors will increase yields has a positive relation with adoption of sensor technology. Perceiving it as a costly measure has a negative relation with adoption. Believing it will increase labor costs and perceiving it as a measure that requires technical assistance are not shown to be significant, but the sign of the coefficients is negative, as hypothesized. Age has a negative relationship with adoption. This was also what we hypothesized. Older growers might not have the horizon to invest in a new technology, especially one that is rather expensive and technically advanced. There were two unexpected outcomes. First, having a college or postgraduate degree has a negative impact on adoption of sensor technology. Second, so does being enrolled in a cost share program. However, being enrolled in a BMP program increases the probability of adoption. The latter was what we hypothesized, since sensor technology is one of the main measures promoted by the Florida BMP manual for vegetable production.

6.5 Descriptive Results for Limburg

As was shown in the previous chapter, we were very limited in our analysis for Limburg due to data limitations. We give a brief description of what we learned from these respondents. None of them uses drip; and only one grower uses flood irrigation or seepage. The others all use a variation of a sprinkler system. We asked them about the barriers to adoption of efficient irrigation. Table 6-5 shows the findings.

Three respondents indicate that they practice rainwater harvesting, one recovers tailwater, and one uses reclaimed water. Four growers indicate that they use WLSAD, and seven use weirs to increase the water level. Twelve growers apply land leveling and fifteen use measures to increase the soil structure. Of the respondents, 61 percent have experienced drought with moderate damage, and 11 percent think the future water availability will be very problematic. One third of the respondents indicate that they have been asked to cutback water use at least once.

If we compare Florida and Limburg based on the limited information we have, we can state that in the Netherlands measures to improve the soil structure as well as the WLSAD seem to be more commonly adopted. Also, more growers in the Netherlands indicate that they have experienced drought with damage. They are also more pessimistic about future water availability than their counterparts in Florida. In both groups approximately one third of the respondents has been asked to cutback water use.

Table 6-1. Stated reasons for not having adopted micro-irrigation in Florida.

Barrier	Percentage of growers who agree
The crop or field conditions are not appropriate	58 %
The improvement will not cover the costs	30 %
Cannot finance the installation costs	18 %
Won't be farming long enough to justify improvements	18 %
Permit may be revised downward	13 %
It requires assistance	10 %
It is not a priority	8 %
It costs too much time	8 %
There is a risk of reduced crop yield	7 %
The future water availability is uncertain	6 %
The landlord won't share in the costs	6 %
'Still working on it'	3 %

Table 6-2. Stated effects of converting to micro-irrigation in Florida.

	Yields	Acreage	Water extracted
Reduced	2	3	37
No effect	13	29	6
Increased	31	11	2

Table 6-3. Frequency of adoption of supply augmentation measures.

Supply augmentation measure	Number of growers using it
Tailwater reuse	26
Rainwater harvesting	25
Desalinated water	2
Reclaimed water	1
None	109

Table 6-4. Frequency of adoption of measures to reduce nonproductive water losses.

Measure to reduce nonproductive water losses	Growers for which it would be possible	Growers for which it would be possible and who use it
Lining of a canal or reservoir	24	3
Mulching	42	34
Land leveling	40	35
Alternative freeze protection	44	27
None	72	100

Table 6-5. Barriers to adoption of micro-irrigation in Limburg.

Barrier	Number of growers who agree
The improvement will not cover the costs	9
It costs too much time	7
It is not a priority	6
Cannot finance the installation costs	3
Won't be farming long enough to justify improvements	3
Permit may be revised downward	3
The landlord won't share in the costs	3
The crop or field conditions are not appropriate	1

CHAPTER 7
CONCLUSION AND DISCUSSION

This chapter summarizes the findings of this study in sections 7.1 and 7.2. Section 7.3 then discusses the limitations of the study and recommendations for future research.

7.1 Recapitulation of the Study Design

The main aim of this study was to answer the question:

"Which factors influence adoption of drought adaptation measures among field vegetable producers?"

We aimed to answer this question for two study areas: Florida and Limburg. In order to answer this question, several sub-questions had to be answered. First, we had to understand how to conceptualize the drought problem and how it affects field vegetable production. Then we had to understand the main water policies governing agricultural water use. Third, we had to make an overview of drought adaptation measures that could be applied in Florida and the Netherlands. Fourth, we had to summarize previous research and make a conceptual model to explain adoption. Fifth, we had to design, test, and distribute a survey. Sixth, we had to choose the empirical model to test the data. Seventh, we had to estimate the model with the data and draw conclusions from the results.

There is a plethora of literature analyzing the determinants of adoption decisions. This study differs from these studies in two ways. Most studies that look at climate change adaptation focus on arid regions; but this study focuses on areas that have been characterized as water-abundant, but which are experiencing increasing pressure on their water resources. Additionally, the study combines the insights of several types of adoption studies and uses different types of analysis to explain adoption.

7.2 Summary

This sections summarizes the main findings of each chapter of the study.

7.2.1 Drought Problem

Around the world demand for water is on the rise. A growing world population, increasing incomes, and increasing concern for the environment have increased the pressure on limited water supplies. This is especially true for densely populated areas such as Florida and the Netherlands. Meanwhile, worldwide demand for food is increasing. Florida and the Netherlands both have an important field vegetable sector, which relies on sufficient quantities of high-quality water. However, the developments described above, combined with the projected changes in climatic conditions, increase the risk of drought damage. Moreover, both areas have an important production season during the driest part of the year, and occurs for a large part on sandy soils with low water retention capacity. Field vegetable production is thus very vulnerable to the effects of drought. Climate change projections add to this vulnerability.

In both areas, but more so in Florida, support programs exist to help growers adopt measures that can reduce drought risk, increase yields, and provide beneficial impacts on the environment. This study aimed to find out which factors influence adoption of these measures, in order to provide insights that can help improve policy targeting.

Moreover, one of the main adaptation measures that growers can take, depending on their production system, is to adopt efficient irrigation. However, an increasing number of studies document how efficient irrigation can actually increase water consumption. We therefore also wanted to explore this issue in the state of Florida and in the province of Limburg.

7.2.2 Agricultural Water Policies

In both the Netherlands and Florida water policy has a history of change, which reflects the difficulties inherent in managing water and specifically water ownership. In both areas water policy as it relates to agriculture is managed by water management authorities at the regional level, which are supervised by the province, state, and national (and for the Netherlands also the European Union) level.

Growers in both Florida and Limburg who intend to use ground or surface water for irrigation generally have to inform the regional water management authority to either submit a notification or apply for a permit. Moreover, growers need a permit to drill a well, although supervising this is difficult. During drought conditions the water management authorities in both areas can install irrigation bans. This means agriculture is especially vulnerable during drought conditions. In both areas growers do not pay volumetric water fees, but rather a property levy. This does not encourage efficient water use. However, in both areas support programs exist to encourage water conservation.

7.2.3 Adaptation Measures

The literature showed a multitude of drought adaptation measures. We focused on long term changes in technology and management practices, which we classified as supply augmentation measures and measures to reduce non-productive water losses. The advantages and disadvantages, and when available, their costs were described in chapter 3. However, these often depend on the location of the grower adopting it.

7.2.4 Conceptual Framework to Understand Drought Adaptation

The literature also showed a multitude of studies that aim to explain the decision of a farmer to adopt either a technological innovation or an adaptation measure. We based our research on studies from both strands of literature.

Our model is mainly based on expected utility theory, but also incorporates elements from protection motivation theory, technology acceptance theory, and economic constraint models, and incorporates other elements on which, according to the literature, more research was needed. This included testing for the effects of spatial variables such as soil type, presence of a stream, and spatial contagion.

7.2.5 Empirical Models and Methodology

We based our survey on the variables we identified in the literature review. After obtaining and cleaning the data, we chose to do several types of analysis. First we used an ordered probit model to explain the choice of the level of efficiency of the grower’s irrigation system. Then we used a bivariate probit model to analyze the decision to adopt measures which were grouped in two categories, in order to account for correlations between the error terms across the equations. We were also interested in the factors that influence the intensity of adoption. We therefore modelled this number of technologies adopted in an ordered probit model. We did a final separate probit analysis to incorporate the perceived attributes of the meaures, something we did not do in the other studies.

7.2.6 Survey Analysis Results

Table 7-1 shows the significant variables for each model and the signs of their coefficients. In some cases there is a different sign in parentheses next to the outcome sign. This indicates that the sign we obtained (not in parentheses) was unexpected according to our theory (in parentheses). The table shows that for each group of measures, some turned out to be significant in at least one analysis. In almost all cases the effect was what we, and the literature, hypothesized. Having or wanting insurance was significant and positive in multiple models as was producing berries. The spatial variables did not always match our expectations. This indicates that more research is needed on the precise effects of spatial variables.

7.3 Policy Implications

These results show us that adoption of DAMs may be increased in several ways. For example, policymakers could target older farmers, as older farmers are currently less likely to adopt sensor technology. Additional research may be needed first, to elicit the main reason why a farmer does not adopt sensor technology. If this research were to show that the grower does not think that he or she can justify a large investment on the farm because he/she will retire and does not know someone to take over the farm, then it could be interesting to look for opportunities to reduce the investment costs or help with take-over after the grower retires. Other growers may be encouraged to adopt sensors through a support program that helps with the installation cost, since there is a negative relationship between the perceived costs of the sensor and adoption.

Moreover, growers who have been asked to cutback water use are probably located in a relatively water scarce area. However, they were less likely to adopt DAMs. Therefore, targeting growers in these areas might lead to increased adoption rates, depending on the reasons for growers not to be adopting now.

Current policies and programs that aim to increase adoption of these measures were not shown to be positive and significant, with one exception. This indicates that people may be adopting measures without using the support programs in place. The negative relationship between cost share enrolment and adoption of sensor technology could mean that growers enrolled in a cost-share program are already using other technologies that may function as a substitute for sensor technology.

7.4 Limitations and Recommendations for Future Research

As with all survey research, our study also has its limitations. The primary limiting factor is related to data collection. The models could be better tested with more data, to improve the credibility, validity and generalizability of the results. The limitations in data also limited us in the type of statistical analyses that we could do, and meant we could not do any type of analysis of growers in Limburg.

There may also have been a problem of ‘self-selection’, when respondents who were interested in the topic of the survey were more likely to respond to the survey than other farmers who are not as interested in it. Many of our respondents were contacted through FDACS or extension agents, which could be seen to indicate that they are growers that are more open to innovations in the first place.

In our study we also gave a brief description of the stated effects of converting to micro-irrigation in Florida. The results indicate that micro-irrigation provides many benefits to the farmer, including increased yields and the ability to expand his or her acreage. However, it has to be kept in mind that this might mean that consumptive water use is increasing. More research is needed on this topic, in order to determine if the cost-share programs that promote efficient irrigation as a way to save water should reconsider this idea.

Table 7-1. Significant variables in our results (in parentheses: expected sign).

	Efficient irrigation	Supply Augmentation	Reducing non-productive losses	Number of measures adopted	Sensor technology
FARMER					
Gender			+		
Age					-
Education			+		- (+)
Experience				+	+
IntInsurance			+	+	+
OftUnpr	+				
Crop Diversity	+		+		
FARM					
Under 50,000	+(-)				
Acres		+			
Tenure	+				
Berries	+		+	+	
Treecrops		-			
Cabbage	-				
Leafy Greens	+				
Goosefoot	-			-	
PotatoNightshad				+	
SPATIAL					
Sandy	+				
PeatClay	+ (-)	+ (-)			
NeigbPos	+	+			
Cutback	- (+)			+	
ShortDamage	- (+)				
INSTITUTIONS					
BMP					+
CostShare					- (+)
PERCEIVED ATTRIBUTES					
Costly					-
Yield effect					+

APPENDIX A
QUESTIONNAIRE

Dear Producer,

We need your help.

This survey is designed to ask about your current water use practices and preferred policies in dealing with possible water shortages or variation in water availability. The big benefit to you in completing this survey is that the results **might help influence water use policy** according to your preferences in the future.

Agricultural production is important to the rural economy of XX County, and water management is increasingly important to this industry as it strives for a more profitable and sustainable future. Florida agricultural producers recognize the value of water and have made tremendous improvements in water conservation during the past 25 years. However, increased water use might reduce the future availability of water to your enterprise and increase pumping costs.

We believe that you can tell us about the best ways in which you manage water, as well as help us identify innovative practices in which you might be interested.

Participation in this study involves completing a brief 10 to 15-minute questionnaire containing questions about your operation, water management, and general demographic information. You have the right to discontinue the survey at any time without consequence. You have the right not to answer any question(s). There are no known risks or immediate benefits to the participants. No compensation is offered for participation.

Your identity will be kept confidential to the fullest extent provided by law. Results will be aggregated and only summary statistics such as averages will be reported to the public, keeping your individual information confidential.

If you have any questions about this research protocol or the survey, or if you would prefer to complete a paper copy, please contact Elizabeth van Dijl at evandijl@ufl.edu, Kelly Grogan at kellyagrogan@ufl.edu or your local extension agent. If you have questions or concerns about your rights as a research participant, please contact the Institutional Review Board, IRB02 office which has approved this survey at University of Florida, Box 112250, Gainesville, FL 32611, (352) 392-0433.

Thank you for your time and effort in completing this survey.

We appreciate your investment in the future of agricultural production!

Sincerely,

Elizabeth van Dijl, BSc
Graduate Student
University of Florida

Kelly Grogan, PhD
Assistant Professor
University of Florida

Name of contact person
XX County Agricultural Extension
IFAS, University of Florida

I have read and understand this consent form and agree to participate in this study.

❍ No, I do not want to participate in the study or I am under the age of 18
❍ Yes, I agree to participate and I am over the age of 18

1. **Please indicate which of the following crops you grow (during any growing season in the past year).** *Check all that apply.*

- o Bell pepper
- o Broccoli
- o Cantaloupe
- o Carrot
- o Cauliflower
- o Celery
- o Chinese cabbage
- o Endive
- o Head cabbage
- o Hot pepper
- o Kale
- o Leek
- o Lettuce
- o Okra
- o Onion
- o Ornamental plants
- o Peas
- o Potato
- o Pumpkin
- o Radish
- o Snap or string beans (green beans)
- o Spinach
- o Summer squash (yellow crookneck, yellow straightneck, zucchini)
- o Strawberries
- o Sugar cane
- o Sweet corn
- o Tomato
- o Turnip
- o Water melon
- o Other (please specify) ______________________

2. **What is the (productive) acreage of your operation?** *This also includes nature areas you use for production reasons, but excludes the home site.*

_______ Acres owned
_______ Acres rented or leased
_______ Acres other (please specify) ______________________

3. **What is the overall soil type of your operation?** *Please indicate the dominant soil type(s) on your operation. If you have several soil types on your farm, please select the dominant soil type(s) that is important to your irrigation practices.*

	Clay	Loam	Fine sand	Coarse sand	Muck or peat	Rockland, limestone	Other (please specify)______________
Surface soil type	❍	❍	❍	❍	❍	❍	❍
Subsurface soil type	❍	❍	❍	❍	❍	❍	❍

4. **What is the distance (in feet) from the nearest surface water body (such as a pond, lake, or river) to the closest border of the cultivated land on your operation?** *This excludes swimming pools and marshes.*

_______ feet

5. **Which irrigation system(s) do you currently use?** *Please indicate which percentages of your total vegetable cultivation area are irrigated with the following methods.*

______% Seepage, flood or furrow irrigation
______% Overhead sprinkler irrigation
______% Micro-irrigation (drip or microsprinkler)
______% Other (please specify)_______________
If you use micro-irrigation go to question 6.
If you do not use micro-irrigation go to question 11.

6. Please pick a representative field from your operation where you use micro-irrigation and with the dominant soil type you indicated above, which will be the focus of the next set of questions. Which crop(s) is/are grown on this field?

____

7. Which irrigation system did you use on this field, before converting to micro-irrigation?

- 1. I have always used micro-irrigation on these fields
- 2. Seepage, flood or furrow irrigation
- 3. Overhead sprinkler irrigation
- 4. Other micro-irrigation (drip or micro-sprinkler)
- 5. Other (please specify) ___________________

If you selected option 2, 3, 4 or 5 go to question 8.
If you selected option 1 go to question 11.

8. **How do you think converting to micro-irrigation has affected your production on this field?** *Please answer this question for your chosen representative field and consider total water use, including water used for soil preparation and crop protection.*

	Reduced	No effect	Increased
Crop yields	❍	❍	❍
Acreage	❍	❍	❍
Amount of water used (pumped for example)	❍	❍	❍

If the amount of water used has not changed or has increased go to question 9.
If the amount of water used has been reduced go to question 10.

9. **Which factors explain why your total water use has not changed or increased after shifting to micro-irrigation on this field**?

- ○ I did not reduce water application rates
- ○ Drip irrigation enabled me to shift to more water-intensive (higher-value) crops
- ○ I do not want my water permit to be revised downward
- ○ Other reason (please specify) ____________________

10. Please indicate if the following statement applies to you: **Micro-irrigation enabled me to expand my acreage**.

- ○ Yes
- ○ No

11. **Which of the following reasons explain why you have not (yet) adopted lower volume irrigation?** *Please check all that apply.*

○ Improvements will not cover costs of installation	○ Cannot finance installation costs	○ Landlord will not share in costs
○ It requires assistance	○ Field and crop conditions are not appropriate	○ Risk of reduced yield or poor crop quality
○ Uncertainty about future availability of water	○ Will not be farming this operation long enough to justify improvements	○ Do not want my water permit to be revised downward
○ Investigating improvements is not a priority	○ It takes too much time	○ Other, please specify on the left

12. **Do you apply any of the following measures to increase your water supply?** *Check all that apply.*

- ○ Tail-water reuse: □ Culvert with flashboard riser
  □ Recovery pond/reservoir

- ○ Rainwater harvesting
- ○ Water desalinization
- ○ Use of reclaimed municipal water
- ○ None of the above
- ○ Other (please specify) ___________

13. **Please complete the following table regarding your beliefs about various water conservation measures. Please only answer for the measures that would technically be feasible to implement on your operation.** *The first measure is related to the entire operation, for the other three please consider the representative field you specified above.*

	Do you practice or use it?		Do you think it is costly?			Do you think it requires technical assistance?			How do you think if affects yields?			How do you think it affects labor requirements?		
	Yes	No	No	Moderate	Yes	No	Moderate	Yes	Reduces	No effect	Increases	Reduces	No effect	Increases
Canal or reservoir lining or covering	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
(Plastic) Mulching	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Land leveling	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Alternative freeze protection (wind machine, tunnel, row covers)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

14. **Please complete the following table with your opinions about irrigation planning.** *Please answer this question for a representative field in your operation.*

	Do you use this practice or technology?		Do you think it is costly?			Do you think it requires technical assistance?			How do you think it affects yields?			How do you think it affects labor costs?		
	Yes	No	No	Moderate	Yes	No	Moderate	Yes	Reduces	No effect	Increases	Reduces	No effect	Increases
Soil or plant moisture sensors	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Weather monitoring with weather station	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Variable rate irrigation (irrigating different fields at different rates as opposed to the same for all fields)	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍
Automatic irrigation system with timer or controller	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍

15. **Do you have a consumptive use permit?** (*Not all farms require this.)*

❍ Yes (go to question 14)
❍ No (go to question 15)

16. **When did you acquire your first consumptive use permit?**

______years ago

17. **Have you ever been asked by officials to voluntarily cutback water use, for example during a period of drought?**

❍ Yes
❍ No

18. **Has drought impacted your operation during the past 4 years?** *This refers to the total amount of water of sufficient quality available to your operation, including rain, surface water and groundwater. This does not refer to crop losses due to irrigation equipment failure, or energy shortage.*

❍ No
❍ Yes, but there was no damage
❍ Yes, with moderate damage
❍ Yes, there was substantial damage

19. **What is your opinion on future water availability for your operation in the next 10 years**?

❍ I think it will be sufficient, not problematic
❍ I think it will be mostly sufficient, it might sometimes be problematic
❍ I think it will be insufficient, regularly problematic

20. **How predictable is your water supply?** *Do you know, at the beginning of the growing season, if there will be sufficient water for your operation?*

❍ Very predictable
❍ Sometimes unpredictable
❍ Unpredictable

21. **How do your neighboring farmers feel about water conservation measures**?

❍ Generally positive
❍ Generally negative
❍ Neutral
❍ Don't know

22. **Have you ever taken advantage of the services of Mobile Irrigation Labs (MILs)?** *MILs offer free-of-charge, site-specific expertise in analyzing irrigation systems and informing property owners on how to improve water conservation and use.*

❍ Yes
❍ No, and I am not interested
❍ No, but I am interested

23. **In the past 5 years, did you receive cost-share payments for irrigation improvements**? *For example: from EQIP, the BMP Cost-Share Program, the FARMS Program (SouthWest Florida); and/or the Water Protection and Sustainability Cost-Share Program.*

❍ Yes (go to question 21)
❍ No (go to question 22)

24. **Which cost-share program(s) did you participate in**?

☐ EQIP
☐ BMP cost-share (FDACS)
☐ (mini-)FARMS (SWFWMD)
☐ Water protection and Sustainability Cost-Share Program (SJRWMD)
☐ Other (please specify) ____________________

25. **Please provide an estimate of the percentage of your total cultivated acres irrigated from the following sources**.
______% Groundwater
______% Surface water
______% Collected Rainwater
______% Reclaimed water
______% Other (please specify)___________

26. **What is your gender**?

❍ Male ❍ Female

27. **Please check your highest level of education**

❍ No high school
❍ Some high school
❍ High school diploma
❍ Two year/technical degree
❍ Four year college degree
❍ Some postgraduate school
❍ Postgraduate degree
❍ Other (please specify) ____________________

28. **What year were you born**? __________

29. **Do you have crop insurance**?

❍ Yes
❍ No, I would like to but my operation does not qualify
❍ No, because I am not interested

30. **Do you have a successor, someone who will take over the farm in the future**?

❍ Yes
❍ No

31. **How many years (approximately) have you managed this operation, or a similar vegetable operation**?

_______years

32. **What is your annual total gross sales**?

❍ $0-$9,999
❍ $10,000 - $24,999
❍ $25,000 - $49,999
❍ $50,000 - $74,999
❍ $75,000 - $99,999
❍ $100,000 - $249,000
❍ $250,000 - $499,999
❍ $500,000 - $999,999
❍ $1,000,000 and over
❍ I am not a commercial grower

Thank you for completing this survey. Please feel free to write any comments you have regarding water management in the space below. Your ideas and comments are <u>very</u> important to us.

____
____

Would you like to receive a summary of the results of this study?

❍ Yes
❍ No
If you do, please provide an e-mail address to which we can send the results.

____

APPENDIX B
REGRESSION RESULTS

Table B-1. Effects of explanatory variables on adoption of irrigation efficiency.

			Marginal effect		
	Coefficient	Standard Error	1	2	3
Farmer characteristics					
CollegPhD	-0.555	(0.357)	0.048	0.170	-0.218
ExperienceMedian	0.007	(0.016)	-0.001	-0.002	0.003
WatAvOP	0.853	(0.605)	-0.044	-0.279	0.323
OftUnpr	1.677**	(0.529)	-0.053*	-0.466***	0.520***
Intinsur	0.262	(0.379)	-0.027	-0.076	0.103
CropDiv	0.133**	(0.056)	-0.013*	-0.040*	0.052*
Farm characteristics					
Acres	-0.000	(0.000)	0.000	0.000	-0.000
Plus250	-0.642	(0.425)	0.065	0.183	-0.248
Minus50	0.997**	(0.422)	-0.075*	-0.307*	0.382**
Tenure	0.808*	(0.425)	-0.076	-0.242	0.319
Berries	1.636**	(0.526)	-0.074*	-0.475***	0.549***
Treecrops	0.397	(0.640)	-0.029	-0.129	0.157
Grasses	-0.225	(0.354)	0.022	0.066	-0.088
Cabbage	-1.595**	(0.601)	0.274	0.247**	-0.520***
Otherleafygr	1.765**	(0.714)	-0.095*	-0.501***	0.596***
Goosefoot	-1.687**	(0.738)	0.361	0.132	-0.493***
Spatial variables					
Sandy	1.014**	(0.364)	-0.065*	-0.320**	0.385**
PeatCl	0.840**	(0.380)	-0.061	-0.265*	0.325*
Neigbpos	0.920**	(0.396)	-0.068*	-0.287*	0.354*
Cutback	-0.833**	(0.327)	0.098	0.214*	-0.313**
ShortDam	-1.363**	(0.511)	0.240	0.207**	-0.447***
Institutions					
MILyn	-0.167	(0.400)	0.017	0.049	-0.065
costshare	0.595	(0.449)	-0.044	-0.189	0.234
BMPStated	-0.557	(0.514)	0.075	0.131	-0.206
cut1 _cons	-0.373	(0.586)			
cut2 _cons	1.476**	(0.592)			
N	95				
pseudo R-sq	0.398				

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Heteroskedastic robust standard errors reported. Columns denoted by 1, 2 and 3 give the marginal effects of adopting flood or surface irrigation, sprinkler irrigation, and micro-irrigation respectively.

Table B-2. Effects of explanatory variables on adoption of SA and NPL measures.

	NPL			SA		
	Coefficient	Standard Error	Marginal effect	Coefficient	Standard Error	Marginal effect
Farmer characteristics						
Agesqmedian	0.000	(0.000)	-0.000	-0.000	(0.000)	-0.000
ExperienceMedian	0.021	(0.018)	-0.001	-0.014	(0.016)	-0.001
OftUnpr	-1.085	(0.714)	-0.065*	-0.574	(0.656)	-0.065*
Gender	0.825**	(0.355)	0.020			
CollegPhD	0.588*	(0.306)	0.018			
Intinsur	0.823**	(0.359)	0.026			
CropDiv	0.086**	(0.032)	0.003*			
Farm variables						
Acres	-0.000	(0.000)	0.000	0.000**	(0.000)	0.000
Tenure	-0.676	(0.493)	0.019	0.362	(0.505)	0.019
Berries	0.808**	(0.398)	0.019*			
Treecrops	-0.552	(0.403)	-0.154***	-7.061***	(0.691)	-0.154***
Spatial characteristics						
Sandy	0.043	(0.373)	0.045	0.355	(0.416)	0.045
PeatCl	-0.373	(0.398)	0.068	0.733*	(0.396)	0.068
Stream	-0.381	(0.320)	0.035	0.439	(0.341)	0.035
Neigbpos	0.447	(0.341)	0.096	0.601*	(0.337)	0.096
Cutback	0.488	(0.325)	-0.033	-0.430	(0.345)	-0.033
Institutions						
BMPStated	-0.498	(0.450)	-0.018			
_cons	-2.082**	(0.738)		-1.055*	(0.639)	
_cons				0.570**	(0.219)	
N				92		

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Heteroskedastic robust standard errors reported.

Table B-3. Effects of explanatory variables on intensity of adoption.

			Marginal effect			
	Coefficient	Standard Error	0	1	2	3
CollegPhD	0.237	(0.263)	-0.001	-0.027	-0.058	0.003
ExperienceMedian	0.036**	(0.013)	-0.000	-0.004*	-0.009*	0.000
WatAvOP	0.561	(0.554)	-0.001	-0.043	-0.131	-0.039
OftUnpr	-2.057***	(0.429)	0.121	0.443***	0.103	-0.279***
Intinsur	1.002***	(0.265)	-0.008	-0.136*	-0.221***	0.042
CropDiv	0.071	(0.062)	-0.000	-0.008	-0.018	0.000
Acres	0.000	(0.000)	-0.000	-0.000	-0.000	0.000
Minus50	0.147	(0.286)	-0.001	-0.016	-0.036	-0.000
Tenure	-0.149	(0.401)	0.001	0.016	0.037	-0.001
Berries	1.291***	(0.392)	-0.002	-0.076**	-0.259***	-0.144
Treecrops	-0.484	(0.586)	0.004	0.071	0.110	-0.034
Grasses	-0.153	(0.283)	0.001	0.017	0.038	-0.002
Cabbage	0.185	(0.478)	-0.001	-0.019	-0.046	-0.002
Otherleafygr	0.445	(0.503)	-0.001	-0.040	-0.107	-0.016
Goosefoot	-0.770	(0.445)	0.008	0.123	0.164*	-0.065
Sandy	0.190	(0.344)	-0.001	-0.019	-0.047	-0.002
PeatCl	0.248	(0.284)	-0.001	-0.025	-0.061	-0.003
Neigbpos	0.025	(0.299)	-0.000	-0.003	-0.006	0.000
Cutback	0.575*	(0.293)	-0.002	-0.056	-0.138*	-0.013
MILyn	-0.183	(0.341)	0.001	0.021	0.045	-0.004
costshare	-0.350	(0.472)	0.002	0.044	0.084	-0.013
BMPStated	0.344	(0.556)	-0.001	-0.031	-0.084	-0.013
Gender	-0.035	(0.323)	0.000	0.004	0.009	-0.000
Agesqmedian	-0.000	(0.000)	0.000	0.000	0.000	-0.000
Plus500	0.708*	(0.343)	-0.003	-0.073	-0.168*	-0.010
Cucurbit	-0.277	(0.373)	0.001	0.033	0.067	-0.006
PeasBeans	-0.050	(0.309)	0.000	0.006	0.012	-0.000
Ornamental	0.469	(0.463)	-0.001	-0.040	-0.112	-0.024
Onion	-0.029	(0.580)	0.000	0.003	0.007	-0.000
Malvaceae	-0.264	(0.409)	0.002	0.033	0.064	-0.010
PotaNightsh	0.697	(0.359)	-0.003	-0.069	-0.166*	-0.015
N	101					

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Heteroskedastic robust standard errors reported. Columns denoted by 0, 1, 2, 3, 4, 5, 6, 7, 8 and 10 indicate the marginal effects of adopting the corresponding number of measures.

Table B-3 Continued.

	4	5	6	7	8	10
CollegPhD	0.049	0.020	0.006	0.005	0.004	0.000
ExperienceMedian	0.007*	0.003	0.001	0.001	0.001	0.000
WatAvOP	0.100	0.057	0.019	0.017	0.018	0.002
OftUnpr	-0.268***	-0.073**	-0.019	-0.015	-0.012	-0.001
Intinsur	0.192***	0.074*	0.021	0.018	0.016	0.002
CropDiv	0.015	0.006	0.002	0.001	0.001	0.000
Acres	0.000	0.000	0.000	0.000	0.000	0.000
Minus50	0.030	0.013	0.004	0.003	0.003	0.000
Tenure	-0.031	-0.013	-0.004	-0.003	-0.003	-0.000
Berries	0.155***	0.134*	0.053	0.055	0.071	0.013
Treecrops	-0.098	-0.033	-0.009	-0.007	-0.006	-0.000
Grasses	-0.031	-0.013	-0.004	-0.003	-0.003	-0.000
Cabbage	0.038	0.016	0.005	0.004	0.004	0.000
Otherleafygr	0.086	0.042	0.013	0.012	0.011	0.001
Goosefoot	-0.150	-0.048*	-0.013	-0.010	-0.008	-0.001
Sandy	0.038	0.017	0.005	0.004	0.004	0.000
PeatCl	0.050	0.022	0.007	0.006	0.005	0.001
Neigbpos	0.005	0.002	0.001	0.001	0.000	0.000
Cutback	0.112*	0.053	0.016	0.014	0.014	0.001
MILyn	-0.038	-0.015	-0.004	-0.004	-0.003	-0.000
costshare	-0.072	-0.027	-0.007	-0.006	-0.005	-0.000
BMPStated	0.067	0.033	0.010	0.009	0.009	0.001
Gender	-0.007	-0.003	-0.001	-0.001	-0.001	-0.000
Agesqmedian	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
Plus500	0.137*	0.063	0.019	0.017	0.016	0.002
Cucurbit	-0.057	-0.022	-0.006	-0.005	-0.005	-0.000
PeasBeans	-0.010	-0.004	-0.001	-0.001	-0.001	-0.000
Ornamental	0.088	0.046	0.015	0.013	0.013	0.002
Onion	-0.006	-0.002	-0.001	-0.001	-0.001	-0.000
Malvaceae	-0.054	-0.020	-0.006	-0.005	-0.004	-0.000
PotaNightsh	0.134*	0.063	0.020	0.017	0.017	0.002
N	101					

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. Heteroskedastic robust standard errors reported. Columns denoted by 0, 1, 2, 3, 4, 5, 6, 7, 8 and 10 indicate the marginal effects of adopting the corresponding number of measures.

Table B-4. Effects of explanatory variables on intensity of adoption of sensors.

	Coefficient	Standard Error	Marginal effect
Farmer characteristics			
AgeMedian	-0.095***	(0.028)	-0.024***
Gender	-0.827	(0.863)	-0.153
CollegPhD	-1.092**	(0.544)	-0.302
ExperienceMedian	0.090***	(0.027)	0.022***
Intinsur	1.875***	(0.558)	0.366***
CropDiv	0.038	(0.043)	0.009
Perceived attributes			
SensorExpens	-1.387**	(0.531)	-0.270**
SensorDifficult	-0.192	(0.547)	-0.046
SensorYield	1.244**	(0.504)	0.273**
SensorLabor	-0.267	(0.465)	-0.063
Farm characteristics			
MicroYN	0.756	(0.462)	0.185
Plus250	1.122	(0.714)	0.294
Minus50	-0.321	(0.715)	-0.076
Tenure	1.078	(0.727)	0.267
Grasses	-0.506	(0.509)	-0.121
Institutions			
costshare	-1.651**	(0.761)	-0.283*
BMPStated	2.214**	(0.808)	0.724***
MILyn	0.135	(0.632)	0.034
Spatial variables			
ShortDam	0.181	(0.591)	0.047
Cutback	0.822	(0.525)	0.225
_cons	-0.013	(0.988)	
N	78		
pseudo R-sq	0.520		

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.
Heteroskedastic robust standard errors reported.

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BIOGRAPHICAL SKETCH

Elizabeth Alida van Dijl completed her graduate work under the Atlantis Double-Degree Program in Rural Development and Food and Resource Economics in 2013. The program is a high-mobility international cooperative partnership between the US Department of Education and the European Commission's Directorate General for Education and Culture. It trains specialists in comparative analysis of EU and US agricultural and rural development policies through a 2 year master program, jointly organized by 5 EU and 2 US leadings institutes in agricultural economics and rural development. The program culminates in a Master of Science degree from one of the US universities (here, the University of Florida) and an Erasmus Mundus joint degree, i.e. the International Master of Science in Rural Development. Elizabeth's mobility program included: Gent Universiteit in Ghent, Belgium; Humboldt-Universität zu Berlin in Berlin, Germany; Università degli Studi di Pisa in Pisa, Italy; and the University of Florida in Gainesville, United States.

Prior to her graduate studies, Elizabeth completed a Bachelor of Science degree in International Development Studies at Wageningen University, the Netherlands. Her study program, which was awarded with the honorarium With Distinction, included a specialization in Economics of Rural Development, and a minor in International Land and Water Management.

After finishing her graduate studies, Elizabeth went on to work as a trainee at the Committee of the Regions of the European Union. Elizabeth is a native of the Netherlands.