Adapting small-scale agriculture to climate change

Techniques for coping with increasing droughts in southern India

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Abstract

A major consequence of climate change will be changes in precipitation. Both amount and distribution will be affected and the changes will vary greatly between different places on the globe. In the inland parts of Pudukottai district, located in southern India, as well as in many other places, the result will likely be increased water scarcity and severe droughts, with dire consequences for food security. The aim of this study is to investigate different techniques for adapting small-scale agriculture to these changes in precipitation, focusing on rainfed agriculture in dry areas where water scarcity is a major problem. A mixed method has been used, consisting of a preparatory literature review and a field study in Pudukottai district. The literature review provided an overview of available techniques for dryland farming, whereas the field study examined the sustainability of one chosen technique; *crop and variety selection*. The field study was divided into two parts, partially quantitative interviews with farmers and qualitative interviews with experts working at the organisation Kudumbam. The results when changing to a more drought-tolerant paddy variety or a more drought-tolerant crop (millets) primarily show advantages in all three aspects of sustainability; ecological, economic and social. However, if the effects of climate change will continue or worsen, it is likely that further measures has to be taken to enable future farming in the area.

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Introduction

The fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC) shows that the earth's climate is changing (IPCC, 2013). Shifts in water cycles and temperatures are linked, and IPCC states in the fifth assessment report that it is virtually certain that, in a long-term perspective, global precipitation will increase when global surface temperatures do so (Collins et al., 2013). However, the raise in precipitation will not be globally uniform, some regions will have an increase, some a decrease and in some regions the precipitation will remain unchanged (Collins et al., 2013). There is high confidence that the contrast between wet and dry regions and seasons will increase with temperatures (Collins et al., 2013). Increase in intensity and/or duration of drought is estimated to be likely on a regional to global scale by the late 21st century (IPCC, 2013).

Changes in monsoon patterns and impacts in India

In the fifth assessment report, IPCC explains that the strength and the timing of monsoon rainfalls are related to atmospheric moisture, the contrast between land and sea temperatures, land cover and atmospheric aerosol loadings (Christensen et al., 2013). Due to climate change, it is expected that future monsoonal rainfall will be more intense globally, mainly because of increased atmospheric moisture as a result of increasing temperatures (Christensen et al., 2013). The local effects of this are on the other hand more complex and uncertain, in some areas the precipitation will probably decrease due to weakened tropical wind circulations (Christensen et al., 2013). Turral et al. (2011) describes the difficulties in downscaling global climate models to a local scale in the report *Climate change, water and food security* published by the Food and Agriculture Organization of the United Nations (FAO). One identified problem is that the models often are too coarse to include topographic effects on precipitation (Turral et al., 2011). In the case of this study, localized to the inland parts of Southern India, the local effects of climate change on monsoon patterns and precipitation are important factors.

India is characterized by seasonal monsoonal rainfall (Christensen et al., 2013). Recently, approximately within the last 50 years, a weakening tendency in mean rainfall and regional redistribution have been observed during the Indian summer monsoon (June-September) (Christensen et al., 2013; Chung and Ramanathan, 2006; Annamalai et al., 2013). These tendencies can be partially explained by factors as increased black carbon and/or sulphate aerosols in the atmosphere having a cooling effect (Chung and Ramanathan, 2006), land use changes (Niyogi et al., 2010) and rising sea surface temperatures affecting the circulations and the distribution of rain (Annamalai et al., 2013). An increase in monsoon break days has been observed, which is in line with the overall decrease in annual rainfall over India approximated by IPCC in the fifth assessment report (Hijioka et al., 2014). In spite of recent observations, all models and scenario projections made by IPCC show a future increase in seasonal mean rainfall during the Indian summer monsoon (Christensen et al., 2013; Hijioka et al., 2014). Normal monsoon years are likely to become less frequent in the future and inter-annual variability as well as extremes will increase according to some models (Christensen et al., 2013). These changes in monsoon patterns imply that some of the impacts of future climate change in India likely will be increased precipitation (Christensen et al., 2013) and variability with increased droughts as well as floods (Turral et al., 2011).

Agriculture and food security

According to Turral et al. (2011), climate change will have an impact on both rainfed and irrigated agriculture across the globe and the rural poor will be disproportionately affected (Turral et al., 2011). In contrast to irrigated agriculture, rainfed agriculture, which accounts for more than 80% of the global crop area (Turral et al., 2011), relies exclusively on rainfall as its source if water (Khanal et al., 2014). Rainfed agriculture is especially exposed to the impacts of climate change, specifically in the mid-latitudes of the globe where productivity is prone to droughts (Turral et al., 2011). Identified future problems related to the agricultural sector are increasing annual surface evaporation with increasing temperatures (Turral et al., 2011), decreasing soil moisture and more agricultural droughts (Collins et al., 2013). The long-term climatic risks in connection to agriculture and water use are however not known with certainty (Turral et al., 2011). Nevertheless, one big challenge in the future is the likely reduction in water supply that will lead to conflicts of interests, such as the conflict between water for irrigation and agricultural use and the environmental pressure this possesses on surface- and groundwater (Turral et al., 2011). This dilemma will, according to Turral et al. (2011), be actualized in semi-arid regions with limited groundwater, such as the monsoonal Indian sub-continent. The current status in this region is characterized by low productivity and over-exploitation of surface- and groundwater resources (Turral et al., 2011). Turral et al. (2011) estimates the vulnerability to future climate change to be high in this region and the adaptability to be only low to medium.

FAO (2003, p. 29) defines food security as:

> "Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life."

The anticipated climatic impacts on water and water management will affect food security (Turral et al., 2011). This is in line with the results presented in the fifth assessment report, where the estimation is that climate change will probably affect food security by the middle of the 21st century (IPCC, 2013). Both IPCC and FAO conclude that this impact will not be globally uniform (IPCC, 2013; Turral et al., 2011). According to the results presented by IPCC (Hijioka et al., 2014), the largest population of food-insecure people are projected to be located in South Asia. Turral et al. (2011) states that regions that are most at risk are those that already are at the edge of climate tolerance and where this edge will be further pushed and regions that presently are stressed by economic, social and biophysical factors (Turral et al., 2011). The regions that are identified as the most vulnerable are South Asia and Africa where large populations with limited economic means resides and productive land as well as water resources are parsimonious (Turral et al., 2011).

Tamil Nadu

The state of Tamil Nadu is situated in the southeast parts of India (see *Figure 1*) and has a climate of mainly tropical semiarid type (Bal et al., 2015). The location of the region makes it very vulnerable to extreme weather conditions with frequent flooding in the coastal districts and severe droughts in other districts (Bal et al., 2015). The topography of the state consists of coastal and inland plains, which constitutes more than half the area of the state, and hills in the west (Jeganathan and Andimuthu, 2013).

Figure 1
Map over India, showing Tamil Nadu in orange (Wikimedia Commons1)

The average annual rainfall in the state is about 950 mm distributed over approximately 50 days (Bal et al., 2015). However, rainfall over the coastal areas is much higher than rainfall over inland areas since the rainfall-causing systems during the northeast monsoon, the principal rainy season, move westward from the Bay of Bengal, first reaching the coast of Tamil Nadu (Bal et al., 2015). The annual rainfall is not evenly distributed throughout the year but has both inter-seasonal and intra-seasonal variability (Bal et al., 2015). The state depends on precipitation from two different monsoon seasons; the southwest monsoon from June to September and the northeast monsoon from October to December (Jeganathan and Andimuthu, 2013). Jeganathan and Andimuthu (2013) estimate that the northeast monsoon constitutes 55 % of the total annual rainfall, while the southwest constitutes only 24 %.

There are many uncertainties when projecting changes in precipitation but the general comprehension is, as mentioned earlier, that annual rainfall in India will increase (Christensen et al., 20113). When zooming in on the state of Tamil Nadu however, there are slightly different results regarding future projections of annual precipitation. Jeganathan and Andimuthu (2013) project an increasing trend in the total annual precipitation with certain seasonal variation. The months of June to November, practically the two monsoon seasons, are projected to have increased annual rainfall while the months of December to May are projected to have a decrease in rainfall. According to Bal et al. (2015) however, there are indications of a decrease in total annual precipitation with some exceptions in high rainfall areas for the state of Tamil Nadu. Furthermore, Bal et al. (2015) shows indications of an average increase during the northeast monsoon (October-December) and a general decrease during the southwest monsoon (June-September). Both Jeganathan and Andimuthu (2013) as well as Bal et al. (2015) expresses the large uncertainties with projections regarding precipitation however, Jeganathan and Andimuthu (2013) stating that the model used is unable to capture local-scale variation.

Aim and research questions

In relation to the effects on precipitation caused by climate change and the risks for future food security, the aim of this study is to investigate different techniques for adapting small-scale agriculture to these changes. Focus will be on rainfed agriculture in dry areas where water scarcity is a major problem. Through a literature review we will present an overview of available techniques for dryland farming. A field study will be performed in southern India, Tamil Nadu, to analyse the sustainability of one technique, namely "crop and variety selection", and observe future challenges for farming in the region. The technique was chosen for several reasons. Firstly, crop and variety selection is a main working area for Kudumbam. Secondly, it is expressed as a very important factor in literature (Mallikarjunarao et al. 2015; Palaniappan et al., 2009). Lastly, it was the technique that was easiest to isolate from the other techniques used in the area. The study is based on the following questions, of which the second one focuses on the famers' perspective.

> What techniques are available for adapting small-scale agriculture to climate change, focusing on water scarcity?

> What advantages and disadvantages are there, for the chosen technique "crop and variety selection", when considering all three aspects (ecological, economic, social) of sustainability?

All measures, methods, technologies etc. discussed are for the sake of simplicity called techniques, whether they are arrangements to collect rainwater or methods for cultivating with less water. In this study, small-scale agriculture will be defined as farming without advanced and expensive techniques for the purpose of selling yield at the local market or keeping it for domestic use. The actual size of the land is therefore not as important as the way that the land is farmed and for what purpose, although the land commonly is quite small.

Study site

The location for the fieldwork performed in this study was the inland area of Pudukottai district in Tamil Nadu (see *Figure 2*). Studies describing the local precipitation in this area do, to our knowledge, not exist. Statistics from recent years are difficult to access, due to insufficient data and absence of digitalization. Information about the mean annual rainfall in the inland area of Pudukottai district was therefore acquired from Kudumbam. According to Quintal (pers. comm.) and Perumar (pers. comm.) the mean annual rainfall is approximately 600-650 mm. Rain statistics for the years 2013 and 2014 had previously been collected from the local weather station and shows that the precipitation was less than 600-650 mm (Kudumbam, 2015). The two years are both examples of late onsets of monsoon starting in August instead of June (Kudumbam, 2015), which usually is the first month of the southwest monsoon (Jeganathan and Andimuthu, 2013). In 2013 the total amount of rain was 355.6 mm, of which 344.6 mm was received during monsoon season. In 2014 the total amount of rain was 534.1 mm, 369.5 mm of that was received during monsoon season (Kudumbam, 2015).

Figure 2
Map over Tamil Nadu, showing Pudukottai district in orange (Wikimedia Commons2)

The field study was conducted in collaboration with Kudumbam, an organisation working for sustainable rural development in the state of Tamil Nadu, India (Kudumbam, 2016a). It is a non-governmental organisation, financed by private donations as well as donations from international and national networks (John Xavier, pers. comm.). The organisation was founded in 1982 by Dr. Nammalvar and Mr. Quintal and has two main areas of operation: Pudukottai district (inland area) and Nagapattiman district (coastal area) (Quintal, pers. comm.). The organisation focuses on the strengthening of rural, vulnerable farmers and the empowerment of widows, single women and orphaned children (Kudumbam, 2016a). In Pudukottai district, Kudumbam has a main office located in the city of Tiruchirappalli and an ecological farm and training centre, called Kolunji, in the village of Odugumpatti (Kudumbam, 2016b). Kolunji functions as a model farm and aims at being a source of knowledge and inspiration for small-scale farmers in nearby villages, offering trainings and courses (Kudumbam, 2016b). As described previously, the annual precipitation is very low (Kudumbam, 2015), and the region frequently struggles with drought. The soil in the area, a red sandy loam, has gradually been degraded, which also has contributed to the difficulties in farming the area (Perumar, pers. comm.).

Among other things, Kudumbam works in several projects with issues concerning sustainable agriculture, food security and adaptation to climate change (Quintal, pers. comm.). One major aspect in this context is the importance of crop and variety selection (Quintal, pers. comm.). Kudumbam promotes the re-introduction of traditional, native varieties and crops which have advantages in coping with climate variabilities, like drought, compared to the hybrids introduced during the Green revolution in the 1960s (Quintal, pers. comm.). During this period there was a shift in cropping patterns in India, rice and wheat replaced pulses, millets and sorghum as the dominant food crops and new high-yielding varieties (HYV) of rice were introduced (Singh, 2000). Although the varieties introduced during the Green revolution have lead to increased productivity and food security (Gupta and Seth, 2007), there are some downsides reported in literature (Gupta and Seth, 2007; Singh, 2000). Evidence is emerging that the intensive cultivation of HYV of rice with Green Revolution technologies (including irrigation and intensive use of fertilizers and pesticides) has led to low soil fertility and low organic content in the soil, depleted groundwater resources and degradation of the soil (Singh, 2000). In excess of these effects, intensive cultivation of rice and wheat have lead to exacerbating problems with weeds as well as resistance to herbicides (Malik et al., 1998 as cited in Gupta and Seth, 2007). To ensure food security in the future, these issues must be addressed (Singh, 2000).

Methodology

The material for this study was collected through both a literature review and a field study. The literature review was made prior to the field study to answer the first research question regarding available techniques for adapting small-scale agriculture to climate change, focusing on water scarcity. The field study, which answers the second research question regarding the sustainability of the chosen technique “crop and variety selection”, was divided into two parts; structured, partially quantitative interviews with farmers and semi-structured, qualitative interviews with staff members working at Kudumbam. Interviews with staff members consisted of one preparatory background interview and two finishing follow up-interviews. As from now, the three are referred to as expert interviews.

Consequently, mixed methods have been used. To use both a quantitative and a qualitative approach to confirm the result of a study is called triangulation (Bryman, 2002). Triangulation has been implemented to increase the credibility of the results (Bryman, 2002), motivating the choice of doing both partially quantitative interviews with farmers and qualitative interviews with experts. Another reason for this choice of method is the aim to capture an interdisciplinary perspective, including ecological as well as economic and social aspects. The prospects of succeeding with this can increase when different kinds of respondents are interviewed. The literature review served as a foundation for the field study, the main emphasis in the discussion and the analysis will therefore be on the field study.

Theory

The United Nations (UN) (World Commission on Environment and Development, 1987) defines sustainable development as:

> “..the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.”.

It is generally accepted that sustainable development consists of three important areas; ecological, economic and social sustainability (UN, 2010). The term sustainable development embraces the complexity of their relationship and recognises the interdependent nature between them (UN, 2010). While sustainability is intended to include all three areas, it has in the last decades often been described as an environmental issue (UN, 2010). To achieve sustainable development, all three pillars must be addressed. This study has therefore been structured as well as analysed accordingly.

Literature review

To collect the material for the literature review, all searches were done in LUBsearch. Only peer-reviewed articles in English accessible at Lund University were included. First, an elementary search was performed using search terms such as "soil moisture" AND "farming techniques". This was done to get an overview of the subject and to find relevant search terms. When relevant search terms and synonyms to those were identified they were combined in such way that merely one search was conducted. The combination finally used was "dry land farm* tech*" OR "dryland farm* tech*" OR "dry farm* tech*" OR "rainfed agricult* tech*" OR "water harvest* tech*" OR "rainfed farm* tech*". The search was done the 4th of April 2016. Articles with publication dates between 2006-2016 were used. The reason for using search terms defined with citation marks was that the technology had to be closely linked to dryland farming (or its synonyms) in some way. A search with AND tech* was tried out, but this search gave a more wide and less relevant result so the combination above was ultimately used.

The result of the defined search described above was 183 search hits, and without the duplicates identified in LUBsearch 89 hits. However, all duplicates were not identified in LUBsearch. The articles were therefore arranged in order of publishing dates and after a manual screening excluding duplicates, the result was 75 hits.

A first screening was then conducted, excluding articles based on titles. The exclusion criterion was articles concerning a too specific crop (e.g. only barley) or geographical area (e.g. mountain areas) or otherwise irrelevant topic. This resulted in 23 articles of relevance. A second screening based on abstract and introduction resulted in seven articles. The exclusion criteria for this process were articles that did not concern agriculture, articles concerning just one technique and articles aimed at large, industrial, agriculture since the focus of this study is small-scale agriculture. The collaboration with Kudumbam, who only works with small-scale farmers, further strengthens this exclusion. Also, it is probable that there are major differences between techniques that are possible and suitable to use between large- and small-scale agriculture. The seven articles that were chosen were then studied thoroughly for different techniques, which eventually were categorized and described as the result of the literature review. Other articles used in the result of the literature review are primary sources referred to from the seven selected articles. The only information used from these primary sources is information discussed in the articles selected for this literature review.

Field study

The field study was performed between the 11th of April and 6th of May in 2016. A semi-structured and qualitative background interview (see *Appendix 1*) with the director of Kudumbam was first conducted. This was done to obtain as much information as possible about the work of the organisation and the farmers involved. A second purpose of the interview was to understand the local effects of climate change, such as rainfall patterns. A selection of suitable farmers was then made with the assistance of the field coordinators from the villages. Each field coordinator selected farmers from his or her village based on given criteria. Because of our focus on rainfed agriculture, one criterion was that only cultivation during the monsoon season was of interest. At present, it is impossible to harvest and store enough water to last through the entire drought season (Quintal, pers. comm.). Therefore, farmers depend on other water sources than rain during this season. Due to failing monsoons or late onsets however, water scarcity is a major problem even during the monsoon season (Quintal, pers. comm.). With this criterion, the possibility to focus on rainfed agriculture was increased. Another criterion for the selection of farmers was that all should have changed crop or variety of crop within the last ten years. The change should have been from a more water-demanding paddy variety to a less water-demanding paddy variety *or* from a more water-demanding crop to millets, a less water-demanding crop. A questionnaire for the structured, partially quantitative, interviews with the farmers was then created. This type of interview was chosen for several reasons. The questionnaire provides a standardized model for the interviews that contributes to making the individual interviews as alike as possible (Bryman 2002) This makes it easier to compile the results and review them in a perspicuous way. It also decreases the risk of disparities in ways of expressing questions and interpreting answers between interviewers (Bryman 2002). Lastly, the processing and analysing of the results are also made easier when using pre-coded questions, which are questions with predetermined alternatives, avoiding the work of transcribing and categorizing the answers after the interviews

(Bryman 2002). A member of staff and interpreters reviewed all questions to ensure their suitability in terms of cultural aspects. This was also done to make sure the questions were understandable based on the knowledge of the farmers and to incorporate local expressions.

As can be seen in *Appendix 2,* the questionnaire was structured so as to begin with some practical questions and an introduction presented in simple language and short sentences to ease interpretation. Some basic information was then acquired and it was clarified that the topic of interest was cultivation during the monsoon season. The questionnaire then continued with the pre-coded questions that concerned the change from the old crop or variety to the new crop or variety and finished with a few questions regarding other techniques and future aspects.

During the first field day, three test interviews with farmers that had implemented different kinds of techniques were conducted. This was done to evaluate the questionnaire and to confirm the choice of "crop and variety selection" as the technique to focus on. The questionnaire was then thoroughly revised due to language difficulties that were more extensive than expected. Ten interviews were then conducted during the four following days, each day in a different village. The farmer from the fifth village was interviewed at Kolunji. The villages visited were Kovilveerakudi, Kongathiranpatti, Valiyampatti, Nallathankalpatti and Ulagankathanpatti. All were located in the inland parts of Pudukottai district, within a few kilometres of the village Odugampatti. Farmers consent to participate as well as permission to record and take photographs was always obtained previous to any questions related to the study. Appropriate clothing was always used to respect the local culture. All questions were presented orally and answers were noted on the questionnaire. Interpretation was shared between two Kudumbam staff members and the field coordinator for each village established contact with the farmers and were present during the interviews.

Two semi-structured interviews with staff members at Kudumbam were then performed (see *Appendix 3)*. The purpose was to follow up the results from the interviews with the farmers, to discuss the advantages and disadvantages of the technique "crop and variety selection" in more detail and to get further knowledge about the local climate. The two staff members were chosen for their involvement in projects of relevance and their theoretical knowledge; Mr Ramadass Perumar, consultant at Kudumbam, and Mrs Poppy John Xavier, deputy director at Kudumbam.

Results

Literature review

The different techniques have been categorized into three groups: *in soil rainwater harvesting*, *reservoir storage* and *cropping systems*. *In soil rainwater harvesting* represents techniques that harvest water in situ, that is directly in the soil of the cropping field (including terraces, ridges and trenches, ploughing techniques, planting pits, mulching, increasing soil biomass and tree planting). *Reservoir storage* consists of techniques to capture water in a defined container (including small storage in containers, cisterns and open reservoirs). These two categories have similarities with the categorization of water harvesting techniques made by Bouma et al. (2016). The category *cropping systems* contain techniques that alter the cropping patterns or the choice of crop (including crop and variety selection and intercropping). The reason for the distinction between different types of techniques, i.e. the categorization, is that the categories have different features. A difference between reservoir storage and in soil rainwater harvesting is that reservoir storage makes it possible to apply supplementary irrigation since the rainwater is kept in a container (Rockström et al., 2010). This could be an advantage for reservoir storage techniques when there are severe intra-seasonal dry spells (Ngigi et al., 2005). Another difference between these two types of techniques is investment and maintenance costs (Lasage and Verburg, 2015). In soil rainwater harvesting techniques often require little investment costs, but substantial maintenance costs (cost for labor) since many of them, such as planting pits, have to be remade every year (Bouma et al., 2016). Reservoir storage techniques, on the other hand, are often expensive investments but require relatively low maintenance costs (Lasage and Verburg, 2015). The two categories are also suitable in different biophysical and hydrological conditions (Bouma et al., 2016). In soil rainwater harvesting techniques can capture rainfall at lower intensities and amounts (Li et al., 2000), compared to reservoir storage techniques. According to Mallikarjunarao (2015), referring to Habitu and Mahoo (1999), in soil rainwater harvesting is best suited in areas where rainfall and the water holding capacity is sufficient to meet the requirements of the crop, but more infiltration of water is needed to enhance the soil moisture level. The techniques in the last category, namely cropping systems, are not water harvesting techniques but ways to cultivate with less water. They are therefore in a separate category.

Since this study consists of both a literature review and a field study, certain limitations have been made in the literature review, both due to restrictions in time and in consideration of the location of the field study. Techniques for irrigation have not been included in this study. Consequently, the distribution of water from the reservoir to the fields, or other techniques for irrigation such as drip irrigation, has not been accounted for. Waste water management and use of chemicals as techniques for dryland farming has been excluded. Due to the inland localization, techniques concerning flooding and coastal areas have not been included either.

In soil rainwater harvesting

The purpose behind in soil rainwater harvesting techniques is to enhance water infiltration directly on cropland (Mallikarjunarao et al., 2015). This can be done by different techniques that delay runoff from the fields, reduces evaporation or creates soil surfaces beneficial for absorption of water (Mallikarjunarao et al., 2015).

When cultivating sloping lands, it is important to keep all fields as level as possible (Mallikarjunarao et al., 2015). This can be achieved by using terraces, steeply shaped constructions positioned across slopes, supporting relatively flat terrace beds (Lasage and Verburg, 2015). The design of the terrace aims to control or eliminate cascade runoff to downstream areas and have throughout history contributed to a better control of soil and water (Jebari et al., 2015). The availability of equipment that can move large amounts of soil has now made establishing new terraces easier but has at the same time increased construction costs (Jebari et al., 2015). These construction and maintenance costs are, according to Jebari et al. (2015), the major drawbacks of the system today.

Similarly to terraces, contour ridges and trenches aims to increase water infiltration (Lasage and Verburg, 2015) by preventing runoff (Jebari et al., 2015). The techniques go by many names, contour ridging are in literature often referred to as contour bunding (Mallikarjunarao et al., 2015; Palaniappan et al., 2009) while contour trenches often are named contour furrows (Saoub et al., 2011). Contour ridging is a development from terracing of slopes and consists of soil ridges following the contours of the landscape (Jebari et al., 2015). The ridges are spaced evenly and are sometimes covered with vegetation, while the areas between ridges are cultivated (Jebari et al., 2015). Contour trenches are placed and functions in the same way as contour ridges, delaying runoff and increasing water infiltration (Saoub et al., 2011). Both ridges and trenches have a low investment cost but require yearly maintenance and has a low durability (Lasage and Verburg, 2015). Saoub et al. (2011) emphasizes that ridges are not suitable for all types of terrain and has to be constructed properly to avoid unnecessary maintenance. Ridges can also be effective on flat cropland, dividing the cultivated area into compartments rather than following the contours of the landscape (Palaniappan et al., 2009).

Creating a beneficial soil surface by preparing and ploughing a cropland in specific ways can enhance water absorption. Forming furrows and beds perpendicular to the slope as well as preventing the formation of a crust increases water infiltration (Mallikarjunarao et al., 2015). By creating a rough surface when ploughing, the time for the rain to break down clods of soil and seal the surface is prolonged and therefore the rate of water absorption is increased (Mallikarjunarao et al., 2015). Palaniappan et al. (2009) explains that summer ploughing in southern India, previous to the monsoon season, is an important strategy for farmers in the district, significantly increasing soil moisture and yield. It is however, as Thomas (2008) points out, important to use appropriate tillage practices to reduce the risk of soil degradation. Another soil surface strategy can be to create small planting pits concentrating water from the surrounding catchment area to the planting hole (Bouma et al., 2015). The planting pits can have different shapes, Saoub et al. (2011) demonstrates positive results when using crescent-shaped and V-shaped pits in slightly sloping areas.

Mulching, the spread of any material on the soil surface, can also be used as a means of improving soil moisture by preventing the formation of a crust, making it easier for the water to enter the more porous soil (Mallikarjunarao et al., 2015). A covered surface also reduces evaporation caused by sun, wind and dry air (Mallikarjunarao et al., 2015). Although it may be difficult to keep a permanent cover in dry areas where water limits the production of sufficient biomass, even a small amount of crop residues on the soil surface can enhance soil moisture significantly by reducing wind erosion (Stewart and Koohafkan, 2004 as cited in Thomas, 2008). Mallikarjunarao et al. (2015) explains that the soil can be covered by either a growing crop or crop residues. Crop residues can, however, provide a breeding ground for plant diseases and therefore, crop residues used as mulch should not be related to the succeeding crop.

Water near the soil surface continuously evaporates, drawing up water from further down in the soil, causing loss of soil moisture (Mallikarjunarao et al., 2015). Planting trees and shrubs in conjunction with cropland can reduce evaporation 10 to 30 % by shading the cultivated area and reducing wind speeds (Mallikarjunarao et al., 2015). The reduction in wind speed not only reduces evaporation, but also soil erosion (Mallikarjunarao et al., 2015). When trees and shrubs are planted on ridges between or around cropland they also contribute to consolidate the ridges (Jebari et al., 2015).

Green manuring is the cultivation of a, often nitrogen-fixing, crop that is incorporated in the soil before sowing the main crop (Palaniappan et al., 2009). As Palaniappan et al. (2009) demonstrates it increases soil fertility by returning biomass to the soil and is an effective measure against soil degradation. In addition to increasing soil fertility, green manuring can, in combination with other techniques aimed at increasing soil fertility and moisture, contribute to improved soil water storage (Selvaraju et al., 1999).

Reservoir storage

Reservoir storage are techniques for water harvesting that require overland flow to recharge the reservoir, and it is therefore dependent on intense rainfall (Ngigi et al., 2005). Lasage and Verburg (2015) conducted a literature overview over existing rainwater harvesting techniques and identified two groups of reservoir storage techniques; small storage in container and large storage in container. This categorization will be further used in this report.

Small storage in containers are all above ground techniques that consists of tanks that capture rainwater from a catchment area such as a roof. This includes rain jars, cement jars and stone masonry jars (Lasage and Verburg, 2015). They can be made out of different materials and their sizes are up to 20 m^3 (Lasage and Verburg, 2015).

Large storage in containers can be in open reservoirs or in cisterns. The open reservoir is typically a pond that is hand dug or has developed naturally (Lasage and Verburg, 2015). They can be either for individual households or for community use. Some ponds have lining made out of concrete or plastic to reduce the permeability (Lasage and Verburg, 2015; Bouma et al., 2016). Cisterns are underground, artificial, reservoirs that collect and stores water (Lasage and Verburg, 2015; Bouma et al., 2016). Open reservoirs and cisterns have often been used as traditional techniques. Two examples are earth dams in Tunisia, locally called *tabias* (Jebari et al., 2015) and village ponds in South India (Palaniappan et al., 2009). Tabias play a major role for soil fixation in Tunisia (Jebari et al., 2015). Nowadays many tabias are unfortunately destroyed due to both extreme rainstorms and changes in authority promotion towards larger dams (Jebari et al., 2015). Village ponds in South India are used to collect rainwater and excess runoff water from the fields (Palaniappan et al., 2009). To make the pond a functioning water reservoir it has to be periodically excavated and desilted (Palaniappan et al., 2009). An advantage with the village ponds, according to Palaniappan et al. (2009) is that in excess of being a water reservoir, they can also recharge the groundwater in the area.

Supply of material is a general disadvantage for using all reservoir storage techniques, since they often require materials such as cement, wire and concrete, which often are locally scarce (Lasage and Verburg, 2015). There is a logistic complexity with these techniques and the need for outside help is often a requirement (Lasage and Verburg, 2015). Lasage and Verburg (2015) identified that cisterns and open reservoirs generally have lower costs in relation to their capacity than smaller tanks for household use. Nevertheless, even though small farming dams are rather costly compared with the water volume gathered, Jebari et al. (2015) argues that they can be of great socioeconomic importance due to the possibilities for local development and contribution to sustainable water-accessibility for the rural population. One advantage of using small storage in containers instead of large open reservoirs is that there rarely are problems with contamination in the closed small containers (Lasage and Verburg, 2015). Other advantages with small storage in containers are that less technical knowledge and money for investment is needed and that the governance is less complicated (Lasage and Verburg, 2015). Governance is necessary when water is to be shared within a village or between villages, which often is the case with ponds and open reservoirs (Lasage and Verburg, 2015).

Cropping systems

Crop and variety selection

Mallikarjunarao et al. (2015) accentuates that choice of crop and variety of crop is a very important factor for conducting dryland farming. Varieties that are suitable for dryland farming should have characteristics such as; short-stemmed and narrow leaf surfaces to minimize transpiration, rapid maturing time to develop before the driest period of the season and deep root systems to utilize moisture better (Mallikarjunarao et al., 2015). This standpoint is shared by Thomas (2008), who declares that switching to shorter duration crops and crops that are more heat, drought- and salinity-tolerant is very important. Palaniappan et al. (2009) could through testing of different varieties of pigeon pea show that there are certain varieties that results in more yield than others in dryland alfisols (red soils) in semi-arid regions in India. They concluded that this was an important way of improving dryland farming in this region (Palaniappan et al., 2009).

A way to choose a suitable variety that is drought-resistant is to use participatory plant breeding, which is selecting for specific adaptations in the target area and involving the participation of farmers in the process (Ceccarelli et al., 2004 as cited by Thomas, 2008). This is, according to Thomas (2008), necessary in preparation of more extreme climate events and to raise awareness of the genetic variation in plants suitable for dryland farming.

Intercropping

Intercropping, to use one main crop and other crops as intercrops (Palaniappan et al., 2009), is a way to use inter-row moisture in a more efficient way (Mallikarjunarao et al., 2015). One main crop is sown, and two or more intercrops are sown in between (Mallikarjunarao et al., 2015; Palaniappan et al., 2009). Mallikarjunarao et al. (2015) claims that this should be of routine practice when farming in dry conditions. Double cropping (sequential cropping) is another method of intercropping where one crop is firstly sown and then later in the season a second crop (Palaniappan et al., 2009). Within areas with bimodal rain patterns and rainfed conditions, the productivity could be greatly enhanced by using this method instead of monocropping (Palaniappan et al., 2009). Thomas (2008) indicates that there is a need to develop new cropping systems instead of unsustainable monocropping systems. This could also be a way to increase the income of farmers (Thomas, 2008).

There are suggestions that including new varieties, using double cropping and adapting sowing dates could completely compensate for increasing temperatures while making water-use more efficient (Iglesias and Minguez, 1997 as cited in Thomas, 2008). These adaptations could, according to Thomas (2008), also cope with inter-annual droughts.

Field study

As mentioned earlier (see *Theory*), this study has been structured as to treat each pillar of sustainability separately. The three are however closely linked and several questions could as easily be discussed in one category as in another. This provides further evidence as to why all three aspects are important. The purpose has not been to achieve the most correct classification of each discussed topic and the result should therefore be considered in its entirety.

Table 1
Shows size of farm, change of crop or variety, time of change and water source for the ten interviewed farmers.

	Size of farm (acres)	**Change of crop or variety**	**Time of change (years ago)**	**Water source (other than rain)**
Farmer 1	1	Crop	7-8	-
Farmer 2	3	Variety	7	Well
Farmer 3	20	Variety	2	-
Farmer 4	2	Variety	2-3	-
Farmer 5	44	Variety	10	Well
Farmer 6	12	Crop	5	Well
Farmer 7	2	Variety	1	Well
Farmer 8	10	Variety	7-8	Well
Farmer 9	2	Variety	1	Well
Farmer 10	4	Variety	10	-

Table 1 shows some basic facts about the interviewed farmers. Size of farm varied between one and 44 acres, one acre being approximately 0.4 hectare. Two farmers had changed crop whereas eight farmers had changed variety of crop. The change had been done within the last ten years. Four farmers depended only on rainwater for the cultivation of discussed crop whereas six used well water for supplementary irrigation. All farmers had changed crop or variety from a more water-demanding crop or variety to a less water-demanding crop or variety. The farmers that had changed variety of crop had changed from one paddy variety to a more drought-tolerant paddy variety. The farmers that had changed crop had started cultivating millets instead of a more water-demanding crop. The most common reason for changing, according to the interviewed farmers, was water scarcity. Other reasons were "less labor", "less crop diseases", "increased income" and "to increase soil fertility".

Table 2
Shows the result from the pre-coded questions with the ten interviewed farmers. All questions concern the change from the old crop or variety of crop to the new crop or variety of crop.

	Positive answer (farmer is satisfied)	**Neutral answer**	**Negative answer (farmer is dissatisfied)**
Water demand	9	0	1
Soil fertility	8	1	1
Yield	8	1	1
Pests, crop diseases, weeds	9	1	0
Ability to sell	8	1	0
Income	7	1	1
Workload	6	4	0
Total result	9	1	0

Table 2 shows the result from the pre-coded questions from the interviews. In these questions the farmers have assessed the change from the old crop or variety to the new crop or variety. *Table 2* is structured so as to show all positive results in one column, all neutral answers in one column and all negative answers in one column. For water demand, pests, crop diseases and workload the positive answer is a decrease. For soil fertility, yield, ability to sell and income the positive answer is an increase. The negative answer is the opposite of these answers and the neutral answer represents no change or that the respondent did not know. The total result of the change is positive if it has been for the better and negative if it has been for the worse. The answers are thus positive if the farmers were satisfied and negative if the farmers were dissatisfied.

Ecological sustainability

Overall, the results regarding ecological aspects from the interviews were positive (see *Table 2*). Nine out of ten farmers answered that the water demand had decreased with the new crop or variety of crop. Eight farmers experienced that changing crop or variety of crop had increased soil fertility, one that the soil fertility was unchanged and one that it had decreased. Eight farmers expressed that the yield had increased with the change, one that the yield was unchanged and one that the yield had decreased. None of the farmers had experienced an increase in pests, crop diseases and weeds, one of the farmers expressed that it was unchanged and the rest had experienced that the problems had decreased.

The farmers used several other techniques for harvesting water and conserving soil moisture in their fields. All interviewed farmers used compartmental ridging, locally called bundings (see *Figure 3*). Other techniques that they used were intercropping, mulching, summer ploughing, green manuring and other local measures to increase soil biomass, tree planting and village ponds.

Figure 3
Compartmental ridging, locally called bundings (photo by authors).

In contrast to the result from the interviews with farmers, it was expressed in the semi-structured interviews with the experts that the yield usually decreases when changing to a more drought-tolerant paddy variety. Compared to hybrid varieties, the yield is low the first years, and then increases. This could, according to Perumar (pers. comm.), be explained by the fact that many farmers, simultaneously as they changed crop or variety, also started using many of the above-mentioned techniques to enhance soil moisture. The techniques are, in addition to beneficial for soil moisture, also closely linked to soil fertility. The implementation of the techniques and the change of crop or variety are often the result of an initiated cooperation with Kudumbam and could have concealed a decrease in yield.

Economic sustainability

The results of the economic aspects from the quantitative part of the interviews were also primarily positive, as can be seen in *Table 2.* Eight farmers answered that their ability to sell parts of the yield had increased, while one farmer answered that there had been no change. Seven farmers also stated that they had an increased income, one that there had been no change and one had experienced a decreased income. One farmer cultivated only for domestic use, hence the two questions just mentioned each have nine answers instead of ten.

All farmers but one sold parts of their yield but in varying amounts, the quantity ranged from a few bags to the entire yield of the discussed crop. The local market was the most common place for this purpose, but some farmers had buyers coming to their home. According to experts (John Xavier, pers. comm.), increased difficulties in selling the yield could be a possible disadvantage, leading to economic consequences, when changing crop or variety of crop. This is, however, mostly due to social aspects and will be discussed further in *Social sustainability.*

When farmers were asked what they would like to do to improve their situation if they had more money, the most common answer was that they would like to increase use of, and deepen, their open wells and/or borewells. Other measures were to invest in machinery, to increase hired ploughing, to implement drip-irrigation and sprinklers. One farmer was unable to answer this question and argued that it would be impossible to farm if the droughts continued.

When changing crop or variety, the investment cost can be either an advantage or a disadvantage depending on what you cultivate. A low investment cost, which is the case for drought-tolerant paddy varieties and millets, is an advantage compared to some other measures that farmers speculated about, such as deepening wells or investing in machinery. For measures like these, farmers need to take loans. According to one expert (John Xavier, pers. comm.), there is presently a very limited opportunity for poor farmers to take loans with reasonable interests from big, national banks. Due to this, farmers turn to private moneylenders and are forced to take loans with very high interests that they eventually cannot pay back.

Social sustainability

Lastly, the results from *Table 2* also show that the farmers answered mainly positively when asked if there had been a change in the workload. Six farmers expressed a decrease in workload and four that there had been no change. None of the farmers had experienced an increase in workload.

Women's work mainly consisted of planting, harvesting, weeding and other similar activities, while men's work consisted of more physically demanding work such as ploughing and constructing bundings. When the six farmers that had experienced a decrease in workload were asked for whom the workload had decreased, one farmer answered that the workload was less for women, four answered for both men and women and one did not specify for whom.

All farmers that were interviewed owned their own land. The interviewed farmers were five women, four men and one pair of a mother and her son. Only one woman did not answer that the responsibility for the farming activities was shared with, or completely in the care of, a male relative. When men were asked for responsibility over the farming activities they were, with one exception, either responsible in their own right or shared the responsibility with another male relative. One man gave the answer that he was responsible with his wife. The levels of education of the interviewed farmers were more or less evenly spread from no education up to one master degree. Men generally had higher education than women. Number of family members ranged from three up to twelve, with one not specified but possibly larger than twelve (three brothers with families). One farmer was not able to feed the family, whereas nine were able to. All farmers had received information about changing crop or variety of crop from Kudumbam. Additional answers were "own experience" or "from the agricultural department".

In one of the expert interviews (John Xavier, pers. comm.), the supply of seeds was expressed as a possible disadvantage when changing crop or variety. Once farmers had acquired seeds, they were therefore encouraged to grow their own seeds to ensure access for next season as well as creating a possible extra income. Another disadvantage was found in cultural aspects, more specifically people’s attitude towards what they eat. John Xavier (pers. comm.) argued that the Green Revolution changed the Indian diet and that there is a continuous scepticism to growing other crops than paddy. Slowly, farmers and consumers are starting to accept millets and other crops, but the resistance in convincing people to change crop is still an obstacle.

Discussion

Methodology

Mixed methods have been used in this study, consisting of a literature review, structured and semi-structured interviews. One could argue that this is a rather complicated method and there are both advantages and disadvantages with this approach. It might cause difficulties in visualizing the total result but it also includes many different perspectives. The reason for choosing this method was, as previously stated, the aim to capture an interdisciplinary approach.

The chosen search terms and their arrangement in the literature review could accidentally have excluded some relevant articles. As an example, articles with expressions such as "technologies for rainfed agriculture" were excluded due to their reversed word order compared to our search term "rainfed agricult* tech*". The chosen method was however necessary to limit the number of search hits.

Regarding the field study, some weaknesses have been identified. Firstly, it is always a problem when you have to use interpretation, since all information acquired is second hand information. Two different interpreters were used when interviewing farmers and the translation of our questions into the local language, *Tamil*, could therefore differ between the interviews. There were also extensive language difficulties with one of the interpreters, and without knowledge of the local language we cannot be sure that the interpretation was correctly performed.

The two interpreters were of different age and gender, one being a young woman and the other an older man. This could, due to cultural aspects, be of importance, especially when the respondent was a woman and the interpreter an elderly man. As a result of social hierarchy, it is possible that the women did not speak freely with men present, which often was the case in this study with one male interpreter and husbands or other male relatives present. The interviews were rarely conducted in private, rather with several onlookers, which is common when preforming fieldwork in India (Heyer, 1992). According to John Xavier (pers. comm.), it is difficult to avoid this problem, since it is regarded as very impolite to ask someone to leave the interview situation, especially as a guest in their home. Lockwood (1992), describing research preformed in Tanzania, argues that social relationships such as gender ideologies and the gender of the person asking the questions might influence the answers obtained in an interview. Nevertheless, we did not find gender to be of critical importance since we could not identify that the answers differed as a consequence of this. In other field studies preformed in Tamil Nadu it has even been described as an advantage to have male research assistance when the interviewer is a woman, since this could work as a counterweight (Heyer, 1992). However, if the study was performed again and if it was possible to influence the choice of interpreter, the question of gender should be considered. Another factor that might have influenced the results was the presence of the field coordinator that sometimes intervened with the interview. The field coordinator was present, as mentioned earlier, to establish contact with the farmers. In that perspective it is an advantage, but it could also be a potential problem if the farmers felt pressure to give answers that would satisfy the field coordinator and the interpreters, all of them having changed crop or variety of crop on the initiative of Kudumbam. This problem is known as "social desirability", the respondent give the answer that he/she thinks is the most socially accepted (Bryman, 2002). There might have been such tendencies in this study. This could be an explanation to the result regarding the yield, which will be further analysed in the following section.

Bryman et al. (2002) states that one important factor is that all respondents are given the same alternatives to each question, and that has been the case for all questions in this study. The pre-coded questions in the structured interviews had three possible answers; a positive answer, a negative answer and a neutral answer. The questions were always presented with the positive and the negative answer as given alternatives; the neutral alternative was only given when the respondent had observable difficulties in answering the question. The purpose behind this was to keep the questions as short and simple as possible to ease the interpretation. The ambition was to vary what alternative was mentioned first, either the positive or the negative, but the distribution slightly favoured the positive answer. These formulations may have affected the result. The neutral answer, which was not commonly chosen, could have been negatively affected compared to the other because it was not mentioned. The positive answer could have been positively affected because it was mentioned first in the majority of questions.

Lastly, our selection of respondents resulted in two farmers whom had changed crop to millets and eight farmers whom had changed to a more drought-tolerant paddy variety. Ideally the fraction between these two should have been the same. This outcome is explained by practical circumstances. We did not select the respondents ourselves, Kudumbam chose them based on our given criteria (see *Methodology*), and in this process the language difficulties proved extensive. It was not possible to communicate directly with the field coordinators, who made the selection of farmers, and we cannot be certain that the given criteria were fully understood. Further studies should be performed with a more numerous selection, and with above aspects in mind, to increase the validity of the results and to make them more generalizable.

Ecological sustainability

As can be seen in *Table 2* in the result, the farmers were overall satisfied with changing crop or variety of crop in regard to ecological sustainability. A factor to take into account is that all answers were based on the farmers' own estimations. We have not performed any own measurements or accessed any local statistics on soil fertility, soil moisture and yield in this study. To perform such measurements, we would have needed to be in field for a longer period to observe the change and preferably also during monsoon season (since that is the main cropping season and the focus of this study). As stated in the result of the literature review, crops that are suitable for dryland farming should have characteristics that make them more drought-tolerant (Mallikarjunarao et al., 2015). The positive result regarding ecological aspects could imply that millets and drought-tolerant paddy varieties have more suitable characteristics for dryland farming than the crops and paddy-varieties cultivated previously. Nine out of ten farmers estimated that the water demand had decreased when changing crop or variety of crop. This result is not surprising, since the use of HYV require extensive irrigation (Singh, 2000). Hence, the water demand should decrease when changing to a more drought-tolerant paddy variety or a more drought-tolerant crop. Regarding soil fertility, intensive cultivation of HYV of paddy can cause decreased soil fertility (Singh, 2000). Eight out of ten farmers had experienced an increase in soil fertility since changing to either millets or drought-tolerant paddy varieties and this improvement might be explained by the previously cultivated crops' negative impact on soil fertility. The farmers also expressed a decrease in problems with pests, crop diseases and weeds. The reason for this improvement is uncertain, although there are some evidence described in literature that cultivation of HYV can give exacerbating problems with weeds as well as resistance to herbicides (Malik et al., 1998 as cited in Gupta and Seth, 2007).

One unexpected result from the interviews with the farmers were that eight out of ten farmers expressed that the yield had increased when changing crop or variety of crop. According to Kudumbams own research, the yield usually decreases when changing to a more drought-tolerant paddy variety (Kudumbam, 2015). The reason for this contradictory result can be explained by a variety factors. Firstly, it could have been due to "social desirability" explained in the previous section. If the farmers thought that a positive answer was desirable they might have been affected by this. Secondly it could be due to other, simultaneously implemented, techniques aimed at increasing soil fertility and soil moisture as explained in one of the expert interviews (Perumar, pers. comm.). Although "crop and variety selection" was selected partially because it was the easiest technique to isolate, it is very difficult to completely isolate the ecological impacts of one measure.

Techniques that were used in excess of crop and variety selection were compartmental ridging, intercropping, mulching, summer ploughing, green manuring and other local measures to increase soil biomass, tree planting and village ponds. These are all, except for intercropping and village ponds, techniques that we classified as in soil rainwater harvesting techniques in the literature review. The only reservoir storage technique that the farmers used, according to themselves, were large storage in container (village ponds) and this technique was only used by approximately half of the respondents. Reservoir storage techniques could have advantages in areas with severe intra-seasonal dry spells (Ngigi et al., 2005), and the location of the field study in the inland parts of Tamil Nadu, an area with monsoonal rainfall and intra-seasonal variability (Bal et al. 2015), are prone to such dry spells. Due to climate change the intra-seasonal dry spells might worsen. Therefore, it is of great importance in a future perspective to maintain and develop the village ponds. For the village ponds to work as a sustainable solution, some criteria have to be fulfilled. Firstly, farmers need to have access to the village ponds, some respondents had no channels connecting their farming area to the ponds. There is also a need for sufficient amounts of rainfall during the monsoon season to fully replenish the dams, which has not been the case in recent years (2013-2014), with a total annual precipitation below 650 mm (Kudumbam, 2015). The village ponds were completely dried out during the field study, which was performed in the drought season (see *Figure 4*)

An advantage with in soil water harvesting is that these techniques can capture rainfall at lower intensities and amounts (Li et al., 2000a). All farmers had implemented some, and often many of these techniques. In soil rainwater harvesting techniques can contribute to sustainable farming in the area, but due to the distribution of rainfall throughout the year, reservoir storage techniques are also needed for supplementary irrigation during dry-spells.

Figure 4
Small, dried out village pond (photo by authors).

Economic sustainability

Both the ability to sell and the income have, according to the interviewed farmers, increased when changing crop or variety of crop. However, both of these results are also strongly connected to the yield and if the increased yield cannot be isolated to changing crop or variety, as discussed previously, the results can appear more positive than they really are. The possible difficulties in selling the yield expressed by John Xavier (pers. comm.) could also argue for slightly misleading results. The presence of Kudumbam staff could, as already mentioned, also have affected the results, making farmers answer more positively than they would have in the absence of staff members. To sum up, although we have identified advantages in ability to sell and income with conscious choices in crop and variety selection, there are many uncertainties as to the reasons for the farmers' answers.

As mentioned in the literature review, the investment cost varies between different kinds of techniques. In soil water harvesting is often less costly than reservoir storage techniques (Lasage and Verburg, 2015). As previously stated, reservoir storage techniques should be well suited for the area because of the uneven distribution of rainfall throughout the year. Despite this, village ponds were the only technique in this category currently used by the respondents. This could be explained by too high investment costs or lack of materials, two known factors that limit the utilization of these techniques (Lasage and Verburg, 2015). In soil rainwater harvesting techniques were however commonly used, which in contrast to reservoir storage techniques have low investment costs (Lasage and Verburg, 2015). Cropping systems, more specifically "crop and variety selection", has different investment costs depending on what you cultivate. In this case, when changing to millets and drought-tolerant paddy varieties, the investment cost is low and a clear advantage, but this could quickly change with another choice of crop. The advantage is therefore case-specific and cannot be generally applied for the technique. Due to the financial circumstances, where only very unprofitable loans are available for poor farmers, a low investment cost is essential for any technique to be sustainable in this particular area. This is probably applicable in many similar areas.

Presently, the farmers sold their products on the local market. According to Kudumbam (2015) there could be an advantage in advertising the products as climate-adapted and reach out to markets in nearby states where consciousness and demand for these kinds of products are higher. Although a very local scenario, similar marketing opportunities can surely be profitable in many places and can enhance ability to sell and increase income for farmers. Limitations in infrastructure and other similar administrative factors can however make it difficult to access other markets than the local.

Social sustainability

Although slightly less positive answers compared to other questions, the majority of farmers had experienced a decrease in workload since changing crop or variety of crop. If the change was gender specific, women had benefited from it. We believe this is a very important advantage since women have the responsibility for many farming activities as well as management of the household. FAO (2009) describes that rural women make out the majority of the world's poor and that much of their work is unpaid and therefore not acknowledged as it should. A technique that can contribute in decreasing the workload for women should be especially favoured in comparison with other techniques.

FAO (2009) shows that women have less access to the control over agricultural decisions and income even though they make substantial contributions to the household, which can be confirmed in this study. Our results clearly show that women do not share responsibility for farming activities equally with men even though they take part in the daily work with the farming activities. Only one woman in this study had sole responsibility for the farming activities and she was also the only one that was not able to feed the family. This is in line with the fact that female-headed households are especially vulnerable to economic recession and food-shortages (FAO, 2009). FAO (2009) further argues that social and economic inequalities between men and women undermine food security and agricultural development. To strengthen the position and rights of women must therefore be at highest priority in the development of the agricultural sector.

The access to seeds can in the beginning be a disadvantage when changing crop or variety of crop. It is therefore important with social groups and organisations such as Kudumbam that can assist members in acquiring what they need. Community seed banks and different types of networks can ease the transition but where these are absent, there could be difficulties in spreading the use of the technique. Collaborations like these are not only important to supply seeds but also to spread the knowledge about the possibilities and advantages in cultivating drought-tolerant crops and varieties. Similar organisations and networks can also play a very important role in spreading knowledge about sustainability in relation to the agricultural situation in general. The solutions that the farmers themselves suggested to improve their situation in the future were in many cases not sustainable. Level of education seemed to have no influence over what answer the farmers gave, both highly educated farmers and those with no or little education suggested increased use of groundwater even though it already is over-exploited (Turral et al., 2011). This shows how important it is to educate and encourage farmers to implement techniques that are sustainable in the long-term.

In this study, farmers that had changed crop had started cultivating millets instead of another more water-demanding crop. One disadvantage in changing crop to millets was the difficulty in selling due to low demand. The preference for eating rice is a major cultural obstacle to changing crop in southern India, many farmers express great hesitation to cultivate something other than paddy. Changing paddy variety to a more drought-tolerant variety is a step in the right direction, but one could argue that paddy is far from a suitable crop for the area. Cultivating millets, a less water-demanding crop, should be more profitable but are due to these social factors neglected. Slowly, farmers are beginning to change attitude and see the advantages in changing to crops like millets (John Xavier, pers. comm.).

Conclusion

The overall result from the sustainability assessment of the chosen technique, crop and variety selection, was very positive. The interviewed farmers primarily expressed advantages concerning their change to a more drought-tolerant crop or variety. The found disadvantages, such as difficulties in selling yield and access to seeds, were also obstacles possible to overcome with time. There are many uncertainties when projecting precipitation patterns, but if the current situation with severe water scarcities persists, we do, however, not think that this measure will be sufficient to secure agricultural production and food security in the region. Changing to crops such as millets should be favoured over changing paddy variety since it is a less water-demanding crop and is better qualified to cope with future changes in precipitation. The cultural difficulties in promoting alternative crops to paddy will hopefully decrease and enable a future expansion of millets and similar crops. In addition to adjusting crops, there is a need to develop techniques that can harvest and store water in an efficient way. Further research on sustainable alternatives for rainfed agriculture is essential to avoid the exploitation of groundwater resources. Other techniques identified in the literature review could be of interest in the future, if, for example, the financial situation should improve. The three pillars of sustainability are intimately linked, but despite the difficulties in analysing the three categories separately, the prospect of identifying all advantages and disadvantages is increased when doing so. Therefore, as shown in this study, it is important to consider all three aspects of sustainability when evaluating the suitability of a technique.

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Appendix 1

The semi-structured background interview was organised in the following sections and contained, among others, the following questions:

Kudumbam
This section included questions about the history, size and working areas of the organisation.

When was the organisation founded? By whom?
What are the main working areas for the organisation?
How many employees does the organisation have, how many offices are there and where are they located?
Do you cooperate with other NGOs?

Climate change
Questions that were asked in this section concerned the local impacts of climate change, the precipitation in the area and future challenges.

How do you think Tamil Nadu will be affected by climate change? How will the precipitation be affected? Is the problem mainly variability or total amount of rain? Is drought the biggest problem?
Have you already experienced problems in this area as an effect of climate change? Do you think the changes will be similar in the future?

Agriculture in Pudukottai district
In this section we asked questions concerning the agricultural practise in the area of our field study; the inland parts of Pudukottai district. Criteria for the interviews with farmers were also discussed.

Is most of the agriculture in this area rainfed? Does the farmers use groundwater for irrigation?
How many farmers are you working with? How is the work with the farmers organised?
What are the main techniques that you promote to the farmers?
Do you have access to any local statistics on yield, soil moisture etc.?

Appendix 2

Questionnaire for the structured interviews with farmers:

Date	
Name of interpreter	
Field coordinator of village	

Our names are Felicia and Johanna. We are students of environmental science from Sweden. We are writing our bachelor thesis about adapting agriculture to climate change. Our focus will be farming in dry areas where water scarcity is a major problem. That is why we are here to interview you and other farmers in this area.

This interview will only be used for our thesis. We will not use any names in the report.

Consent to participate	
Consent to take photos	
Consent to record the interview	

1. What is your name?	
2. What is the name of your village?	
3. What is the size of your farm?	
4. Do you own the land? If not, who does?	
5. How many family members are you?	
6. Are you responsible for the farming activities?	
7. Do you have any education?	
8. What crop do you cultivate during the monsoon season (July to December)?	
Clarify that the following questions only will concern cultivation during the monsoon season	
9. Have you changed a) paddy variety or b) crop anytime during the past ten years? When?	
10. Why did you change a) paddy variety or b) crop?	
11. Do you use any other water than rainwater for the cultivation of named a) paddy variety or b) crop?	
12. Is any of your land only rainfed? How much?	

Clarify that the following questions concern the <u>change</u> of paddy variety or crop			
Question	Increased/ more/better	Unchanged	Decreased/ less/worse
13. Do you use more or less water?			
14. Has the soil fertility decreased or increased?			
15. Has the yield increased or decreased?			
16. Do you have more or less pests, crop diseases or weeds?			
17. Do you sell any of the yield? If so, how much? Where?			
18. Are you able to sell more or less?			
19. Has your income decreased or increased?			
20. Are the income and the yield enough to feed your family?			
21. Has the workload decreased or increased?			
22. If changed workload, for whom? Alternatives: women, men or children?			
23. Has the total result of changing been for the better or for the worse?			

24. How did you get the information about changing paddy variety/from … to millets?

25. What do you use to enhance soil moisture in your fields?

26. What do you think could improve your ability to farm this area in the future if the droughts continue or worsen?

27. Is there something in particular that you would like to do to improve your situation if you had more money?

Appendix 3

The semi-structured follow up-interviews with experts were organised in the following sections. The two interviews focused on different aspects due to the respondents' area of expertise.

Inland parts of Pudukottai district
What is the normal annual rainfall for the inland parts of of Pudukottai district? What has the annual rainfall been in the recent years? How is the distribution of rainfall throughout the year?
If experienced changes: do you believe this is due to climate change?
How much of the agriculture in the district (not coastal) is only rainfed?
What is the soil type in the working area (the inland parts of Pudukottai district)?

Change of crop or variety of crop
How many of your farmers have changed crop or variety of crop? Has it been successful?
What advantages and/or disadvantages is there with this technique?
After reading about Kudumbams research, our impression is that a decrease in yield is common when changing to a more drought-tolerant crop or variety. The farmers we interviewed described an increase in yield when changing to a more drought-tolerant crop or variety of crop. What do you think is the reason for this result?
What different features does drought-tolerant crops or varieties have?
Will you continue working with change of crop and variety of crop?

Future perspectives
Is changing crop or variety sufficient for the future challenges or do you suggest other measures?
Is there a future for paddy cultivation in this area?
Many farmers expressed a wish to deepen their wells or drill bore wells. What do you think of this?