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Climate-Adapted Soil Cultivation as an Aspect for Sustainable Farming – Task-Technology-Fit of a Decision Support System

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ABSTRACT

Due to global climate change and its impact on local weather conditions, decision support systems are becoming more important in agriculture. Such systems allow farmers to adapt more effectively to the complex changes affecting their farms. Marginal production sites must apply new tillage strategies adapted to new climatic conditions. Information about proper strategy adjustments is often disseminated through agricultural extension services and journals. A new internet information platform, KlimaBob, which focuses on climate-flexible tillage, was established under the auspices of the Innovation Network of Climate Change Adaptation Brandenburg Berlin. Successful and permanent introduction of such a system requires analysis and verification of its acceptance among individual farmers. This study addresses this need by applying the established task-technology fit approach. A survey was conducted among farmers in the Brandenburg region. The resulting data provided the basis for a structural equation model that explains and evaluates the task-technology fit of the KlimaBob platform. The results indicate that the performance spectrum of the system exerts a strong influence on the task-technology fit when assessed by both the name characteristics of KlimaBob and the individual characteristics of users (for example, time management, technology affinity and risk attitude).

Keywords: Decision support systems, task-technology fit, climate change, arable farming

1 Introduction

As climate change gains in importance, farmers are increasingly being challenged to keep adjusting to changing climate conditions so that key challenges, such as growing global food and energy needs, can be met while, at the same time, farms can remain financially sound and adapt to further challenges on a long-term basis (Murphy and Hommel, 2006; Eitzinger et al., 2009). Especially in arable farming, established strategies and procedures have to be reviewed and in many cases adapted (Smit and Skinner, 2002). This adjustment must always take into consideration local particularities, for climate change can take on completely different forms in different regions of Europe (Kersebaum et al., 2009). Possible results of climate change range from the warming or cooling of certain seasons to shifting amounts of precipitation during the vegetative period to the appearance of periods of drought and extreme rainfall (IPCC, 2007). In future, peripheral places of production in Germany may well be devastated by extreme events (Helmholtz-Gesellschaft, 2010). For regions with low profits, which are not unusual in Brandenburg (Gerstengarbe et al., 2003), it is particularly important to react to changing climate conditions by adjusting crop strategies at an early stage. Moreover, to optimise soil use, it is increasingly important, in addition to choosing the right type and strain of crop, to time sowing as well as fertiliser and pesticide application accurately (Eitzinger et al., 2009). Primarily in regions where plants receive only a limited amount of water due to the low availability of arable land or to the limited rainfall during the vegetative period (Kersebaum et al., 2009), soil preparation that is tailored to the specific locale and conserves water is already exerting a decisive influence on cultivation yields (Eitzinger et al., 2009; Gerstengarbe et al., 2003).

There are various sources of information to aid farmers in their choice of soil management. Until now agricultural journals (O.V., 2009) and agricultural extension services have been important sources (Thomas, 2007). A new way of providing farmers with information for climate-adapted soil management has emerged with the internet platform known as KlimaBob, which was established by the Innovation Network of Climate Change Adaption Brandenburg Berlin (INKA BB). KlimaBob is an online decision-making support system (DSS) that can provide agricultural decision-making aids for soil management that are region- and situation-specific. It is comprised of three components: a data bank system, a model system and a user interface. Using the data bank system, the model system generates optimal management alternatives for the user and presents them visually. The detailed structure of the DSS can be seen on the KlimaBob homepage (ZALF, 2012). This paper seeks to determine to what extent the KlimaBob program meets the needs of users and experts and what impact it has on the acceptance of the fulfilment of demands. This question will be analysed by using the task-technology fit (TTF) model. Farmers in the state of Brandenburg answered a standardised survey regarding the new internet platform and its ability to assist decision-making.

This paper is divided into five sections. The following section will introduce the research model and the proposed hypotheses. The next section (Study Region) will characterise the agricultural situation in the state of Brandenburg and describe the study design. The structural equation model is the focal point of the results section with its identification of various degrees of influence during the evaluation of KlimaBob. Finally, the results of the empirical analysis will be discussed and conclusions derived.

2 Research Model

The TTF model was developed in 1995 by Goodhue in order to identify factors influencing utilised approaches. However, the actual use of informational systems cannot be directly described by it. Goodhue (1995) assumes, rather, that the approach utilised is influenced by the individual user's estimation of the total system's productivity. The model supposes that the estimation of a system's productivity is influenced by three general influencing factors, namely, the task, the technology and the individual. Although the model is set up to allow a multidimensional evaluation, every individual dimension can be quantified. The multidimensional perspective enables one to gain a deep insight into the effects of an informational system, such as the DSS (Goodhue, 1998). The TTF model can be used to determine problems in certain areas of the system and to illustrate the success of alleviating an existing problem (BAROUDI und ORLIKOWSKI, 1988). As seen in Figure 1, both the existing TTF model and the model adapted for the survey comprised three descriptive factors and one dependent factor.

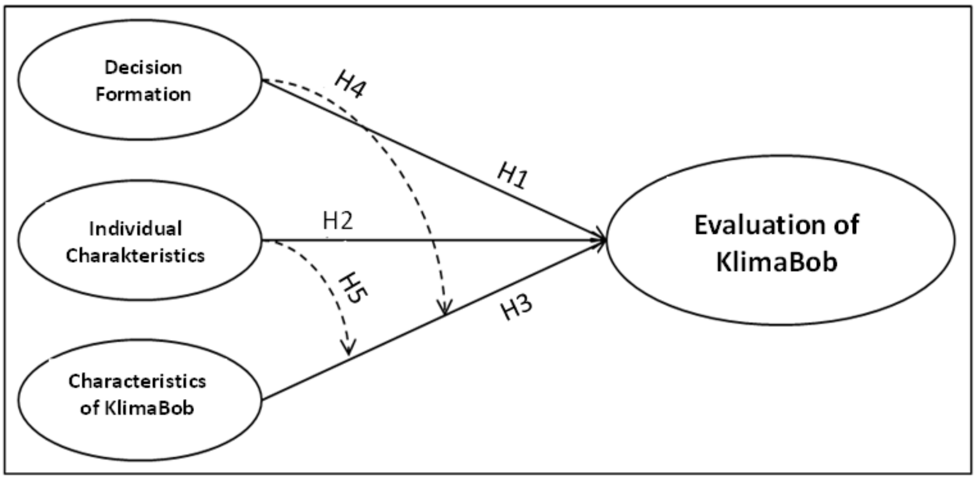

Figure 1: Amount of influence exerted on the evaluation of KlimaBob according to the TTF model
Source: Adaption from Goodhue (1995 and 1998)

Not only the three descriptive factors, but also the dependent factors are constructs which in turn comprise several variables (Fornell and Bookstein, 1982).

The three independent constructs exert a direct influence on the dependent construct Evaluation of KlimaBob. In our model, which corresponds closely to the original model, these three descriptive constructs are labelled Decision Formation (the original called them "tasks"), Individual Characteristics (formerly called "individual") and Characteristics of KlimaBob (previously "technology"). The three research hypotheses (H1 to H3), which were indicated by arrows in the TTF model (see Fig. 1), are as follows:

H1: The construct Decision Formation influences the Evaluation of KlimaBob.

H2: The construct Individual Characteristics influences the Evaluation of KlimaBob.

H3: The construct Characteristics of KlimaBob influences the Evaluation of KlimaBob.

In addition, two of the three independent constructs modify the effects of the influence of the third independent construct. This moderation is determined by the influence an independent construct is able to exert when under the influence of another independent construct. According to this, further research hypotheses (H4 and H5) can be proposed for the present case, which are indicated by arrows composed of broken lines:

H4: Decision Formation modifies the influence of the Characteristics of KlimaBob.

H5: Individual Characteristics modify the influence of the Characteristics of KlimaBob.

3 Study Region

Description of the Study Region

The state of Brandenburg lies in the north-eastern part of Germany and is composed of 14 counties. Roughly half of the land area is involved in agriculture. Of the entire 1.3 M ha area, 78 % is arable land, 21.5 % is grassland and 0.5 % has a different use.

Figure 2: Geographic location of the state of Brandenburg

Source: Authors´ representation

The average size of the 6,700 agricultural enterprises in Brandenburg is 194 ha. The legal form of the enterprise varies from an area of Ø 1,400 ha for cooperatives to Ø 63 ha for individual businesses. Business forms also vary; 76 % are individual businessmen, 10 % partnerships, 10 % LLCs und 4 % cooperatives. The predominant soil is sandy to loamy sand, which influences the choice of crop to be cultivated. Typically early, dry summers and the soil’s inability to store water further limit the cultivation of certain crops. With its average precipitation of 553 mm/a, Brandenburg is roughly 31 % below the national average. In 2010, the soil in Brandenburg was prepared in various ways: 55 % by conventional means, 43.5 % by mulch drilling and roughly 1.3 % by direct sowing (Statistik-BBB, 2011). Taking into account the precipitation situation, the available soil structure and the ways of working the soil in Brandenburg, it can be seen that the use of a DDS such as KlimaBob could definitely make sense in this region.

Study Design

In order to obtain the necessary data, a survey with 32 questions was devised and sent either by regular mail or by email to all counties in the state of Brandenburg. Two hundred copies of the survey were either mailed directly to member business leaders in the INKA BB project or sent to agricultural traders and insurance agents for distribution to farmers. The survey likewise appeared online on the homepage of the Information System for Integrated Plant Production (ISIP). The return rate of the printed form was 34 % (n = 68). The online survey was answered by 24 persons who visited the ISIP site (43 %). Thus, the two methods of collecting data provided a respondent pool of n = 92. At least one respondent from each of the 14 counties in Brandenburg took the survey. The 32 questions were divided into four sections: four personal questions, 14 questions about the agricultural business, seven questions about agricultural advisory services and seven questions about climate-adapted soil management. For each question, the respondents had to choose between alternative pre-determined answers. A five-step Likert scale was used to quantify the opinions and preferences. The scales ranged from "completely disagree" to "undecided" to "completely agree". The Likert scale was chosen in order to obtain responses which could be easily compared, thus facilitating evaluation of the data produced (Schnell et al., 1999).

After processing, a descriptive analysis of the data was carried out using Statistical Product and Service Solutions software (SPSS), Version 18.0 for Microsoft Windows. Evaluation of the adequacy of KlimaBob regarding its task and the five research hypotheses was later performed using the component-based partial least squares (PLS) structural equation procedure. In a two-step approach, the quality of the measurement models is evaluated by their reliability and validity; afterwards the structural model is examined. The software used for the analysis was SmartPLS Version 2.0. M3.

4 Results

Description of the Random Sample

In regard to the subjects' socio-demographics, 92.4 % were male. The average age was 44.3 years, and ages ranged from 23 to 69. The majority were farm owners (59.9 %); 19.5 % were managers with partial ownership, a further 13.8 % were managers without ownership shares, and the rest (6.9 %) were other farm personnel. Of the farms surveyed, 97.7 % employ a conventional management form; in regard to farming type, 48.3 % of the farms can be characterised as mixed and 31.1 % as purely agricultural, while 11.5 % cultivate fodder and 5.7 % are in animal husbandry. The farm managers surveyed were responsible for an average of 784.71 ha arable land and 209.96 ha grassland. Within these two categories, there is great heterogeneity in regard to the area of individual farms (arable land: 3 to 2,600 ha; grassland: 2 to 1,600 ha). When considering the total arable area of all 92 farms, mulch sowing (soil preparation without ploughing) dominated with 49.7 % of the area, followed by conventional soil preparation (ploughing) with 46.1 % and direct sowing (no tillage) with 4.2 %. More than half of the farmland (54.9 %) rotated three crops (monoculture, 6.9 %; rotation of two crops, 9.8 %; rotation of four crops, 22.0 %; rotation of five crops, 6.4 %). The most area was dedicated to the cultivation of winter rye, winter oilseed rape and winter barley.

The majority of respondents (91.0 %) were already aware of available DSS – in this case, ISIP – or had even already used it in farm operations. Consequently, the majority of the respondents from the state of Brandenburg could definitely understand the term DSS, which was very relevant for the evaluation of the following hypotheses as well as the analysis of the fulfilment of expectations on KlimaBob.

Composition of the Constructs and the Quality of the Measuring Model

The measuring model is composed of constructs which are based on the TTF model (see Figure 1). The constructs are measured by observable variables – henceforth referred to as indicators – which are assigned to them. Indicator reliability reflects which portion of the variance in an indicator is explained by the respective construct. In general, more than 50 % of the variance should be explainable (Hair, 1998); in this study, this is the case. Construct reliability and internal consistency reveal how well the construct is measured by the indicators. This can be measured with the quality criterion Cronbach's Alpha (CRA) (Nunnally, 1978), which indicates good reliability for values of 0.6 and above.

Table 1.

Quality values of the constructs and descriptive statistics of the chosen variables

Constructs (incl. Quality values)	Disagree [1] (%)	Undecided [2] (%)	Agree [3] (%)	Average [4]	Standard deviation
Decision Formation (AVE: 0.711; CR: 0.831; CRA: 0.596)					
1. Could you imagine that the use of a support system for making decisions on soil management that is adapted to climate changes could become established in the future and/or that it would be used by farmers?					
a. It is more likely that such information will be obtained from other sources.	6.8	68.2	25.0	3.23	0.64
b. Many farmers have their set way of farming and will not change their methods.	30.4	34.8	34.8	3.04	0.93
Individual Characteristics (AVE: 0.558; CR: 0.787; CRA: 0.592)					
1. Could you imagine that the use of a support system for making decisions on soil management that is adapted to climate changes could become established in the future and/or that it would be used by farmers?					
a. It cannot become established because a large number of farmers are unable to use the internet.	64.8	27.3	7.9	2.34	0.80
2. Would you, in your leading position in farming operations, consult a website?					
a. It is too risky for me to introduce changes on the farm that might result in losses.	57.3	32.9	9.8	2.40	0.87
b. Due to lack of time, I probably will not have time to consult a website.	54.9	34.3	10.8	2.48	0.89
Characteristics of KlimaBob (AVE: 0.593; CR: 0.897; CRA: 0.863)					
1. From your perspective, which concrete decisions regarding soil management should be supported or taken into consideration by a decision support system?					
a. Use/or not of plough, depending on crop	5.7	14.9	79.4	3.89	0.82
b. Depth of particular farming operations (ploughing, cultivating)	2.5	17.7	79.8	3.92	0.70
c. Weather influence	1.2	21.4	77.4	3.90	0.69
d. Demands of the planned crop on soil preparation	1.2	15.1	83.7	4.00	0.67
e. Choice of machinery (e.g. cultivator or short disk harrow).	2.5	20.0	77.5	3.88	0.70
f. Influence of residues (debris) from harvesting (e.g. straw)	0.0	14.3	85.7	4.04	0.57
Evaluation of KlimaBob (AVE: 0.616; CR: 0.823; CRA: 0.692)					
1. Could you imagine that the use of a support system for making decisions on soil management that is adapted to climate changes could become established in the future and/or that it would be used by farmers?					
a. Because the early summer drought greatly influences the yield, I would find additional information from regional studies useful.	2.2	17.0	80.8	4.01	0.75
2. Would you, in your leading position in farming operations, consult a website?					
a. I would look at a website.	8.1	17.4	74.5	3.78	0.85
b. If the suggestions were comprehensibly explained, I would try to apply them to my farming operations.	7.1	26.2	66.7	3.64	0.74

AVE: Average Variance Extracted; CR: Construct Reliability; CRA: Cronbach's Alpha; 1„Totally Disagree“ and „ Disagree“; 2„ Undecided“; 3„ Agree“ and „Totally Agree“; 4 from 1 "Totally Disagree" to 5 "Totally Agree"
Source: Authors' Calculations.

In addition, Fornell und Larcker (1981) speak of good values when construct reliability (CR) is greater than or equal to 0.7. Both quality criteria are met in the analysis at hand (see Table 1). The minimal shortfall of the CRA value (< 0.6) of two constructs can be justified in light of the good construct reliabilities and the limited number of indicators (Garson, 2011). In order to evaluate the validity of the discriminants, it is necessary to ascertain the average variance extracted (AVE) and the Fornell-Larcker criterion (Fornell und Larcker, 1981). The AVE describes the common measured variance between the construct and its respective indicator and should not have a value less than 0.5 (Chin, 1998). This value was obtained for all constructs in the measuring model (see Table 1). The Fornell-Larcker criterion is met when the average measured variance of the constructs is greater than the square of the correlations between the constructs (Fornell und Larcker, 1981). This quality criterion is also met without exception by the values in the model. In addition, the results were tested for cross-loading. Ideally, the loading of an indicator on its respective construct should be greater than its loading on other constructs. In the model, no cross-loading was identified. Therefore, the measuring model shows satisfactory results for all quality criteria.

The Structural Model

The structural model illustrates the connections between the influential factors or independent constructs and the construct which will be an object of the study. It is evaluated by calculating the coefficient of determination of the endogenous variables (R^2) and the degree as well as significance of the path coefficients. The formulated hypotheses were illustrated in the following model by arrows, by which the path coefficients (depicted by broken lines) as well as the standardised beta-coefficients of the regression analysis could be interpreted (Albersmeier und Spiller, 2010). The respective t-values were calculated using the jackknife method. A good structural model is characterised by great explanatory power and statistically significant t-values. The latter were derived via the bootstrapping method with 1,000 resamples. The results of this structural model are illustrated in Figure 3. The analysis shows that 56.8 % of the variance of the TTF regarding KlimaBob can be explained. Regarding the DSS, the TTF is most significantly influenced by the characteristics and capabilities of KlimaBob. Thus, Hypothesis (H3) is confirmed.

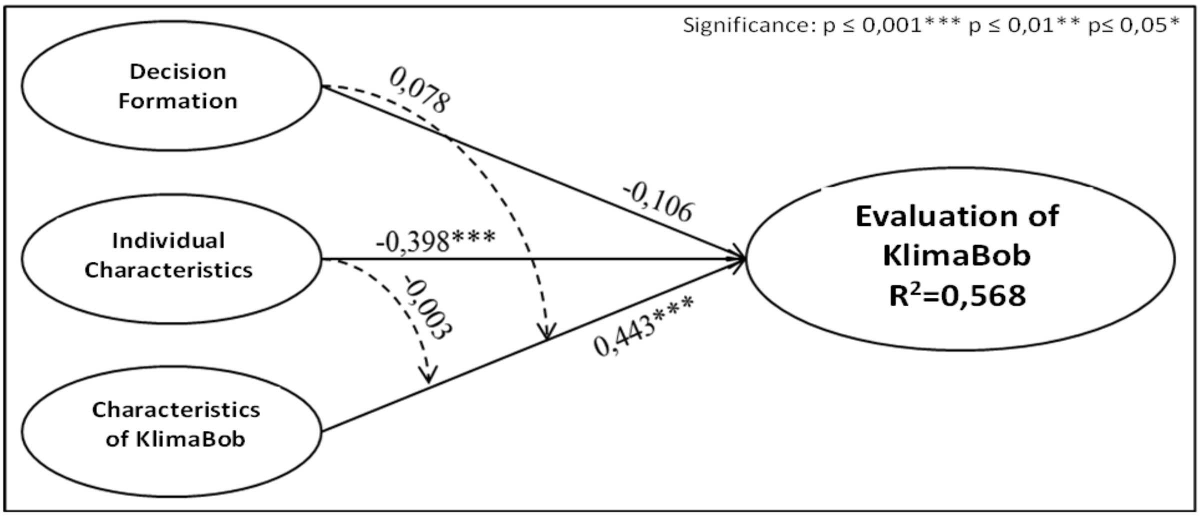

Figure 3. Degrees of influence among TTF model
Source: Authors' Calculations.

According to Hypotheses 4 and 5, the influence of this construct should be affected by decision formation and individual characteristics. However, in the research example, no significant effects were ascertained. Therefore, Hypotheses 4 and 5 can be rejected. The second significant influence is exerted by individual characteristics (H2), such as use of time, interest in technology and approach to risks. Decision formation (H1) does not significantly influence the dependent construct; however, its influence measures only slightly less than significant. In total, two of five hypotheses concerning the DSS KlimaBob could be confirmed in the context of TTF.

5 Discussion and Conclusions

The evaluation of the task of the requirements for the DSS KlimaBob was carried out with help of the TTF model according to Goodhue (1995). The coefficient of determination R2 (cf. Figure 3) which was relatively high for socio-economic analyses, underscores the adequacy of the chosen approach. The overall result of the causal analysis showed that the construct Characteristics of KlimaBob exerted the greatest significant influence on the assessment of the requirements of the DSS KlimaBob. This can be explained by the fact that the evaluation of use of a DSS generally depends on the characteristics of the DSS being aligned to demands. The variables of chosen machinery, long-term weather conditions and demands of specific crops on soil management (see Table 1), which are included in the construct, are among the key factors for success in crop production (Diepenbrock et al., 1999). (Likewise, the optimal choice of machinery for the weather and the proper use of machinery are decisively responsible for the amount of evaporation from arable land (Bodner et al. 2010). Because one of the goals of implementing KlimaBob is to reduce evaporation during future periods of draught, which will probably occur more frequently in early summer in Brandenburg (Helmholtz-Gesellschaft, 2010), the strong positive influence of the Characteristics of KlimaBob on the Evaluation of KlimaBob is not surprising.

The second construct exhibiting a significant effect is Individual Characteristics. The negative influence of the dependent construct Evaluation of KlimaBob is due to the formulation of the three variables (see Table 1). The variables that make up the construct comprise the (partial) inability of farmers to use the internet and a possible lack of time to check the online information. A basic requirement for the use of the KlimaBob is access to the internet. However, a representative survey of German farmers in 2009 revealed that only 68 % had an internet connection (in comparison in 2005: 58 %; O.V., 2009). As a result, despite the expansion of internet service in rural areas (BMELV, 2011), farmers were still below the national average of 73 % for 2009 (DESTATIS, 2009). Just as important as the technical availability of the internet is how the individual farmer uses it. Farmers use the internet primarily to check weather data, do online banking and obtain information about the market and about machinery and product markets. The frequency of internet use by farmers is also important for the success of KlimaBob. This study showed that roughly half of the respondents used the internet many times during the week, while the other half used it daily (Vennemann und Theuvsen, 2004). As a result, sufficient time is spent online to provide the opportunity to work with the internet-based DSS KlimaBob.

Similarly, the willingness of farmers to integrate new operating procedures is reflected in the construct Individual Characteristics. When using KlimaBob, farm managers would generally have to make two changes to their farm operations. First of all, they would have to integrate the DSS KlimaBob into their decision-making process. Secondly, they would need to be willing to implement potentially new soil management methods in response to KlimaBob's recommendations. However, it is well known that proposed changes to traditional farming methods, especially concerning cultivation practices (e.g., sustainable soil management), are often very slow to gain acceptance among farmers, even if those changes are advantageous when viewed objectively (Mußhoff et al., 2009; Baudoux, 2001; Jessel und Jacobs, 2005). According to the respondents, over half of the area in question (53.9 %) is no longer farmed with soil management, but with techniques such as direct sowing or mulching, resulting in decreased water needs and optimised erosion prevention. In consideration of the fact that these techniques make more efficient use of the production factor water, which is limited in some regions, one wonders why currently only half of the area uses conservational farming methods. Possible reasons might be that the sowing with mulch might encourage the establishment of more snail and mice populations, which could promote the transfer of fusaria in grain crop rotation, and the growth of weed grasses (Pekrun und Claupein, 1998; Klingenhagen und Frahm, 2001).

The results of the Evaluation of KlimaBob were important regarding its task fulfilment in order to be able to reach the goal of a successful implementation of the DSS. The non-confirmation of research hypothesis H1 also reveals that the respondents in Brandenburg are relatively open to KlimaBob specifically and new sources of information and new farming methods in general. However, diverse studies have revealed that acceptance of DSS among farmers is sometimes low (Carlsson und Turban, 2002; Rosskopf und Wagner, 2006; Bahlmann et al., 2009). These studies have cited causes such as technical reasons and problems in the concept as well as with understanding and use. A further disadvantage of the DSS was often the great amount of time needed beforehand to enter required monitoring data. In light of this and of past somewhat sobering experiences, a very good marketing concept must be developed, and the program must be carefully adjusted to the needs and expectations of potential later users in order to win over as many users as possible (Arens et al., 2011). Previous experience also suggests that it is absolutely necessary for developers and users to continually exchange information and knowledge until such a DSS becomes established (Mccown, 2002).

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