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ABSTRACT

Conservation agriculture (CA) is often quoted as a beneficial resource-saving technique for dryland agriculture, but its large-scale implementation is frequently hindered by the lack of farmers' acceptance. To date, few studies have investigated the impact of spatial factors, costs and benefits and regional agro-system differentiation on adoption of CA. This study therefore aims to assess the impact of these factors through a case study in the North Ethiopian Highlands. One hundred and eight farmers of eleven villages surrounding an experimental plot were interviewed in order to identify their knowledge and acceptance of the technique. The results show that several spatial factors play a role in CA acceptance. The lack of knowledge on the resource-saving technique proved primarily dependent ($R=-0.73$) on spatial impedance with the innovation source and on the strength of sociospatial networks. Next, a consumer model showed that perceived costs and benefits seem to balance each other. Finally, some agronomic traditions were identified that are related to the regional agro-ecosystem, which are not favoring the implementation of zero-tillage practices. Since this study identified acceptance problems related to several spatial and regional factors, future CA adoption schemes must allow better regional differentiation optimized to local contexts and conditions.

Key words: diffusion of innovation, random utility model, reduced tillage

1. INTRODUCTION

Farm households in Tigray (a region in northern Ethiopia), basically implementing subsistence agriculture, face chronic and transient poverty (Fredu et al., 2010). To contribute to the solution of these problems, conservation agriculture (CA) practices have been introduced on experimental plots on Vertisol in the May Zegzeg catchment (Dogua Tembien district) since 2005, with the aim of reducing runoff and soil loss and thereby improve crop yield (Tesfay et al., 2012). According to the FAO (2010), “CA is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. CA is characterized by three principles that are interlinked, namely continuous minimum mechanical soil disturbance, permanent organic soil cover, and diversification of crop species grown in sequence or association.”

The CA technique has known beneficial and detrimental effects (FAO, 2010). The technique allows to strongly decrease labour input (ploughing, weeding) and capital input (oxen). In addition, it is gender-friendly (alleviates the weeding burden which is traditionally taken by women and children). Direct costs include, among others, crop residues that are left on the land (loss of livestock fodder), the guarding of crop residues, the 'transaction costs' of dealing with conflicts over these residues and possibly herbicide costs. With regard to environmental impacts, the use of herbicides must be evaluated against decreased livestock pressure and increased water conservation.

This study is based on three theoretical paradigms that are often neglected in research on the acceptance of conservation agriculture: (i) diffusion of innovations, (ii) cost-benefit analysis and (iii) agro-ecosystems. A large body of research has focused on (perceived) cost-benefit analysis of CA. A meta-analysis of 130 empirical studies in Sub-Sahara Africa, Latin America and the

Caribbean shows that the benefits of CA are generally outweighing the costs, with a better net advantage compared to conventional agriculture (Knowler, 2003). Adoption of CA is less investigated than its costs and benefits, and there are few if any universal factors that can explain the adoption (Knowler & Bradshaw, 2007). A meta-analysis of 31 studies on CA adoption worldwide shows that most studies explain CA acceptance using several farm characteristics (Knowler & Bradshaw, 2007). For Africa, these studies include for instance Okoye et al. (1998), Clay et al. (1998), Agbamu et al. (1995) and Somda et al. (2002). The factors include farmer and farm household characteristics (age, education, etc.), farm biophysical characteristics (farm size, slope of the fields, etc.), and farm financial management (income, hired labor, etc.). A number of other studies linked CA acceptance to several ‘exogenous’ factors (input prices, output prices, etc.). Although some studies focus on CA adoption and another group of studies compare (perceived) CA costs and benefits, there have been no studies ‘linking’ these two perspectives. Hence, most of the studies link CA acceptance with a number of empirically-derived farmer characteristics, without taking the farmers’ decision process (rationally weighing perceived costs and benefits) into account. The decision of a farmer to choose to adopt CA resulting from a rational reflection on costs and benefits would frame acceptance rates within microeconomic customer theory. According to the customer (choice) theory, a decision is made by a consumer based on a comparison of preferences (*in casu* costs and benefits). For an in-depth discussion on the customer theory, the reader is referred to Train (2003). However, full rational decision making is only possible under the condition of perfect information or knowledge (Gibbons, 1992).

Information and knowledge are diffused through complex spatial patterns (Dolde & Tirtiroglu, 1997; Thrift, 2005), which fits well within the framework of the theory of innovation diffusion. This research field investigates how new ideas spread in a population (Rodgers, 2003). The

theory was conceived in the mid-20th century by Torsten Hägerstrand (1957), and was applied in numerous studies of several disciplines, such as studies on the adoption of agricultural production technologies for row crops by Corn Belt farmers in the USA (Atwell et al., 2009). It is generally accepted that innovations have a strong location-specific component, with geographical proximity and spatial accessibility as important factors (Massard and Mehier, 2009). However, people primarily adopt an innovation based on subjective values and social norms diffused through interpersonal networks, rather than as a result of rational reflection on scientific data (Coleman et al., 1957; Rodgers, 2003; Ryan and Gross, 1943). The example is often set by opinion leaders, and subsequently diffused via social networks. Atwell et al. (2009) emphasize that in all land resilience theory, ecological and social systems are inextricably linked. Hence, although very few studies examine the spatial complexities of CA adoption (for an exception, see Fuglie & Kascak, 2001), it seems likely that (socio)spatial patterns reflecting the diffusion of knowledge (information) on CA can strongly influence its adoption.

Finally, it can be observed that CA has already been applied at a large number of locations, and therefore under very different socioeconomic, geologic and climatic conditions (Ahuja et al., 2006, Giller et al., 2009, Araya et al., 2012). Farming production systems under such a large number of varying local agronomic circumstances can be defined as local “agro-ecosystems” (see Conway, 1986). Such socio-ecological systems include varying “environmental conditions, farming practices, soil conservation, and several actors, policies, institutions and governance structures” (Prager et al., 2010). However, in contrast to this important regional differentiation in agronomic production systems, the FAO consistently proposes a one-size-fits-all system for CA implementation (requiring minimum soil disturbance, permanent organic soil cover and diversification of crop species). Hence, it needs to be investigated which features of local agro-

ecosystems (e.g. agronomic habits, local traditions etc.) are inconsistent with the one-size-fits-all FAO model, and consequently are negatively affecting the acceptance by farmers.

Given the above-discussed research gaps, and framed within the above-mentioned theoretical reflections, this paper attempts to link CA adoption (i) to (socio)spatial factors in the framework of the diffusion of innovations theory; (ii) to perceived costs and benefits, in the framework of the consumer theory; and (iii) to regional agronomic sensitivities in the framework of the agro-ecosystem theory.

2. METHODS AND MATERIALS

2.1 Study area

The capital of Dogua Tembien is Hagere Selam, a little city surrounded by several smaller villages located in the May Zegzeg catchment (MZZ). The village of Hechi is situated approximately 4 km east of Hagere Selam, at an altitude of 2200 m, and is only accessible on foot (Figure 1). The village has an area of 580 ha and has around 200 houses with approximately 1000 inhabitants. More than 90% of its population lives from agriculture, and farmers' crop yields range from 500 to 1500 kg ha⁻¹ (Naudts, 2002), which depends on yearly rainfall, soil type and land management applied (e.g. stone bunds, conservation structures); (Pender & Gebremedhin, 2004). Most farmers own some cattle (notably oxen), grazing freely over most lands during the dry season (October till March or until June in the absence of ample soil moisture during the *belg* rain (April to May)). Cattle provide traction while ploughing, but produce also milk, meat and manure. Furthermore, cattle function as a saving buffer for times of extreme drought; and can be considered as a status symbol.

According to Naudts (2002), an average household in Hechi owns some oxen, 5 goats and 1 donkey. They own or rent on average 0.75-1.2 ha cropland, with 60% of the households having

less than 1 ha. Common crops are wheat (*Triticum*), barley (*Hordeum vulgare*), *hanfets*, which is wheat and barley sown together, and teff (*Eragrostis tef*); and *Sorghum bicolor* and maize (*Zea mays*) if there is belg rain (the short rainy season from April to May). All croplands are ploughed with the local ard plough or *mahresha*. In Hechi, 43% of all farmers own only one ox. Since one ox is not sufficient to use the *mahresha*, two neighbours commonly share their oxen, albeit that traction can come from a cow or donkey too.

The lower parts of the MZZ catchment (Argaka) consist of Mesozoic sedimentary Antalo limestone. Crops in the Argaka area are sown in the first half of July. The crop production system alternates between wheat or barley and leguminous crops such as lentils or grass peas, or sometimes leaving the plot fallow for 1 year. When rains start early, many farmers plant sorghum or maize here (Nyssen et al., 2008). A layer of hard Amba Aradom sandstone, visible in the landscape as a steep cliff of red rock, is situated upon these strata. On top of the sandstone, subhorizontal Tertiary basalt lavas are present in the upper Zenako area (Nyssen et al., 2008). These areas are planted following a cereals–beans crop production system.

FIGURE 1

2.2 Application of CA in the catchment

CA has been applied at an experimental station located in the Zenako area. The treatments executed since 2005 at the experimental station consist of two main types: (i) Plain Tillage (PT) which is ploughed three times without leaving residue and (ii) 40 cm permanent beds with 30% residue keeping, with limited tillage in the adjacent furrows only (CA, a technique named *derdero+*). All the ploughing and reshaping of the beds and furrows is done using the local plough or *mahresha* (Nyssen et al., 2011) and weeds are controlled with herbicide. The non-selective herbicide applied was glyphosate (N (phosphonomethyl) glycine), which was sprayed at

2 L/ha 3–4 days before planting, but after the emergence of the weeds. The plots are equipped with runoff collector trenches where daily runoff and sediment yield are measured. In 2005-2012, significantly less ($p < 0.05$) soil loss was recorded for CA as compared to PT. Similarly, the mean runoff was $931 \text{ m}^3 \text{ ha}^{-1} \text{ y}^{-1}$ from plots with CA, as compared to $1041 \text{ m}^3 \text{ ha}^{-1} \text{ y}^{-1}$ for PT (Tesfay et al., 2012).

In addition to the experimental plots, nine farmers in the same catchment practiced the *derdero*+ type of CA on their farms for the last four years. The information coming from these farmlands was added to this study, since such data represent a real-world practical implementation of CA. They received payment as a participation incentive and as a help to curb initial adoption costs. As all contact farmers have their homestead in the village of Hechi (4 km E of Hagere Selam, Tigray), the research focused on this village (innovation source), its cultivated lands and on the nine contact farmers. These farmers were interviewed in order to identify their knowledge and acceptance of the technique. In addition, also a representative sample of 108 farmers with crop growing experience of eleven surrounding villages was interviewed in-depth, in order to identify knowledge and acceptance.

2.3 Scientific setup and hypotheses

Given the research gaps discussed in the introduction (section 1), the scientific set-up can be visualized (Figure 2), and refined towards the following hypotheses:

Hypothesis (Hyp-A1): Spatial factors have an impact on CA adoption, since the decision to adopt CA requires sufficient information on the technique, which is spatially diffused. Several indices can be calculated in order to test this hypothesis (section 2.4).

Hypothesis (Hyp-A2): Social networks influence CA adoption, since the perception on costs and benefits is mediated by opinion leaders and interpersonal relationships. Qualitative information from semi-structured interviews can be used in order to test this hypothesis (section 2.3).

Hypothesis (Hyp-B): Although adoption is often linked with empirical farmer characteristics, it is *in se* the farmers' decision (rationally weighing perceived costs and benefits) that explains the decision to apply CA. A consumer choice model can be used in order to test this hypothesis (section 2.6).

Hypothesis (Hyp-C): Due to several local complexities in “agro-ecosystems”, the one-size-fits - all approach for CA is insufficiently adapted to local conditions, which is not favoring adoption. Qualitative information from semi-structured interviews can be used in order to test this hypothesis (section 2.3).

FIGURE 2

2.4 Semi-structured interviewing on adoption of innovations

In order to study the diffusion theory and the diffusion of acceptance, fieldwork was executed between July and September 2011. We carried out a total of 119 semi-structured in-depth interviews with individuals, with the assistance of a translator who was familiar with both the study area and its inhabitants. Most farmers were interviewed on their farmlands or sometimes at their farm. Interviews were semi-structured, but the results were then analysed quantitatively, a methodology described by Abeyasekera et al. (2000). Nine of these interviews concerned the farmers that have applied the CA technique since 2005 (Figure 3). These farmers were supported by the project, and received advice, herbicide and an annual incentive payment for 30% crop residue compensation. The farmers all live in the village of Hechi, and have their lands both near

their house or at half an hour walk in a large farmed area where aftermath grazing is not allowed and that belongs to the village (area named Zenako). All farmers were asked for their perception on CA costs and benefits and were asked to give an exhaustive list of all advantages and disadvantages, in order to assess a perception analysis of costs and benefits of the technique.

Furthermore, ten surrounding villages in the valley east of Hagere Selam (Figure 4) were investigated, situated at the interface of basalt and limestone areas. Since the main research aim was not to profile the villages, but rather to identify CA diffusion and acceptance, at every village approximately ten farmers were interviewed (Table 1). Since 2005, several CA demonstration sessions were performed at the experimental plot; whereby five people from every village in the valley were invited. Although no statistics are available on the participation in these sessions, it is likely that people living in villages closer to the experimental plot were more represented. Since it is situated on the two geological substrates, the village of Harena was considered as consisting of two separate entities in the framework of this study (an upper part and a part lower in the valley). All farmers were asked for (i) their knowledge of the main aspects of the technique, (ii) their perception on costs and benefits of the technique and (iii) their interest in its future application.

FIGURE 3

FIGURE 4

TABLE 1

Finally, several other interview series were performed. An in-depth interview with a leading officer of the Dogua Tembien district office of the Ethiopian Ministry of Agriculture (DTMA) allowed assessing the local government opinion. All interviews were executed in a way that only

open questions were asked (e.g. ‘give all benefits of CA that you can think of’) and no questions were asked that would provoke desired answers (e.g. ‘do you think CA leads to higher yields?’). Thus, all questions were asked in a non-suggestive way.

2.5 Indicators for the knowledge diffusion

In order to assess the spatial impact on the diffusion process, an impedance proxy measure I_x was constructed for this mountainous area, and calculated for every village x . Spatial impedance can be defined as the contrary of spatial accessibility, meaning “the simplicity with which activities in the society can be reached, including needs of citizens, trade and industries and public services” (National Road Administration, 1998 page 2). The concept is well studied in ‘time geography’ (Neutens et al., 2012), a research field created by the above-mentioned geographer Torsten Hägerstrand based on his ideas on the diffusion of innovations. Accessibility proxies are then derived from (i) a resistance component (distance and cost) and (ii) the attractiveness of the activity centre (Makri & Folkesson, 1999). Based on the literature review of Makri & Folkesson (1999) focusing on spatial accessibility, we constructed an impedance proxy with a resistance component (walking distance and walking effort due to steep topography) and with an attractiveness component. Attractiveness depends strongly on landscape visibility (Lankhorst et al., 2011), which was added to the proxy. This proxy quantifies the difficulty of a farmer in a village x to reach the village of Hechi. Choice and weight of the variables used to construct the impedance proxy are based on research-informed knowledge in the valley. Hence, the impedance proxy I_x for a village x was constructed as:

$$I_x = d.v.\Delta H \quad \text{standardised to range [0-1]} \quad (1)$$

where:

d is the walking distance (in km) on footpaths from the village x to Hechi (the innovation source), as measured in ArcGIS;

v is the ‘visibility’ of Hechi from the homestead x , indicating the spatial knowledge of the area (0.5 for visible, 1 for invisible);

ΔH is the absolute height difference (in m) due to ups plus the height difference due to downs between Hechi and village x . It is a proxy for effort of transportation to be made for going to Hechi.

The obtained I_x was standardised with the highest value (I_x of Khunale) to obtain values ranging from 0 to 1.

Secondly, in order to construct a CA knowledge proxy measure V_x for every village x , questions were asked concerning the knowledge of the technique to 108 farmers in the eleven villages. The four aspects of CA (see FAO, 2010) were evaluated, and weighted using an analytic hierarchy process (Saaty, 2005). The components included: (i) notion of the zero-tillage component; (ii) notion of the permanent furrow component; (iii) notion of the residue-keeping component; and (iv) notion of the herbicide component. Sincerity of the answers was tested by asking the farmers to show the ploughing technique on their fields or to draw the tillage movement on the ground. Farmers who had notion of all four components were attributed a ‘knowledge score’ $i = 1$, and farmers who knew some but not all components 0.5. Farmers who knew no components were attributed a knowledge score $i = 0$. For every village x the relative percentage F_{ix} was calculated by dividing the number of farmers with score i by the total number of interviewed farmers in village x . Then the village knowledge proxy V_x was calculated as:

$$V_x = 1 F_{1x} + 0.5 F_{0.5x} + 0 F_{0x} \quad \text{with range [0-100]} \quad (2)$$

2.6 Acceptance analysis

According to Knowler & Bradshaw (2007), a rich research tradition exists linking farmer-related variables to the adoption of agricultural innovations. In general, logit or probit models are usually used to link relevant variables to adoption (Feder et al., 1985). As illustrated in section 2.3 this paper seeks to identify relevant variables that represent the perceived trade-off of costs and benefits. Therefore, the interest in CA of the farmers was linked with the perceived costs and benefits, and a binomial random utility model (logit type) was constructed. In order to analyse the acceptance constraints, farmers were asked to name all benefits and disadvantages they know. Then, the number of farmers in a village x who perceived certain benefits or costs was calculated as a proportion of the number of interviewed farmers in that village x , and these proportions were then correlated with the indices V_x and I_x . Erenstein and Farooq (2009) used a similar methodology to identify the factors associated with zero tillage adoption in India and Pakistan. U_k is the utility that farmer k obtains from choosing for CA and depends on the characteristics of the farmer, some of which are observed by the researcher (z) and some are not (ε_k):

$$U_k = z + \varepsilon_k \quad (3)$$

The farmer chooses for CA, $\pi = CA$, if $U_k > 0$ and he does not chose for CA, $\pi = PT$, if $U_k \leq 0$. The unobserved ‘irrational’ error term ε_k is assumed to have a logistic distribution. Then, following Amemiya (1985), the probability of choosing for CA is:

$$P(\pi = CA) = \frac{1}{1 + e^{-z}} \quad \text{with } z = \sum_{k=0}^{k=n} \beta_k x_k \quad (4)$$

where x_k represent the independent variables and β_k represent the regression coefficients.

With the use of eq. (4), relevant household characteristics that influence the choice for CA can be identified. The dependent variable ‘interest’ gets value 1 if the farmer answers positively on the question whether he would implement CA soon on his fields, without any monetary support from the project. The variable gets value 0 if the farmer answers negatively, is doubtful or if he appears to be interested mainly in the monetary support. Independent variables include (i) knowledge (values 1, 0.5 or 0 for knowledge score), (ii) benefits (total number of mentioned environmental, labour, and capital benefits), (iii) costs (total number of mentioned costs), (iv) substrate lithology (1 for limestone, 0 for basalt), and (v) the impedance proxy I_x (Eq. 1). Also, a sixth independent variable ‘distance from the house of the farmer to his farmlands’ (in minutes; as asked during the interviews) was incorporated, albeit travel time for a specific journey is always somewhat uncertain (Xu et al., 2008).

However, because not all decisions can be grasped by a random utility model, these choices would depend on the noise factor ε_k in Eq. (3). Hence, some other constraints exist that explain this ‘unpredictable’ part of the farmers’ viewpoints, in general related to the ‘mind-set’ of farmers in a traditional agro-ecosystem. A qualitative analysis of the semi-structured interviews provided some insight into these acceptance problems.

3. RESULTS AND DISCUSSION

3.1 Diffusion of knowledge

3.1.1 Spatial impedance

Both spatial accessibility and social networks can influence the diffusion pattern of the CA innovation. In order to investigate the spatial impact, for every village x , the impedance factor I_x

was calculated using eq. (1) (Table 2). The villages Khunale, Hala and Tsigaba have the highest level of spatial impedance to the CA innovation centre in Hechi.

TABLE 2

Also, the understanding by the farmers of the different components of *derdero+* could be analysed. Remarkable is the fact that the one-time ploughing component (known by 29.6% of the interviewed farmers) is less known than the furrow component (known by 69.4% of the farmers), the litter residue component (known by 68.5%) and the herbicide component (known by 47.2%). Then, for every village x a village knowledge score V_x was calculated with eq. (2) (Figure 5). Knowledge is least in Khunale, Hala and Adikwunti, revealing a link between knowledge and spatial impedance. Indeed a strong (negative) correlation exists ($R = -0.73$) between the knowledge (proxy V_x) and the impedance (proxy I_x). This indicates that people who rarely come in the vicinity of Hechi know very little about the CA experiment.

FIGURE 5

3.1.2 Social networks

Not only spatial factors are important, also interpersonal relations play their role. Interviews revealed that social networks between the village x and the innovation source Hechi can come from kinship, friendship and marriage, as 39.2% of all conventional farmers mentioned such factors as reasons for their knowledge of CA. Also, according to five farmers, the Christian orthodox religious relations and administrative relations between the villages are important. For example, inhabitants of Gebla Emni went in Hechi to church, before the construction of their own

church a few years ago, they celebrate the same religious days, and have common social events. Also the influence of administrative boundaries plays a certain role (for instance Gebla Emni became part of another municipality some 15 years ago). Hence, following Hägerstrand (1953) and Rodgers (2003), this proves the importance of face-to-face contacts in innovation diffusion.

3.2 Constraints for the diffusion of CA acceptance

CA acceptance was first analysed by examining the perception on costs and benefits of CA by the farmers. Benefits and costs named by the farmers of the eleven villages were divided in three main factors of production: the environment; labour; and capital.

3.2.1 Expected benefits

Agronomic (biophysical) benefits mentioned by the interviewed farmers comprises: (i) increased water availability in the furrows; (ii) decreased erosion or soil loss; (iii) softer soil and increased porosity; (iv) increased soil fertility and organic matter content; and (v) less weed after the month of June. In general most farmers are quite positive about the biophysical impact of CA; only one farmer thought the straight furrows would speed up the water flow. Some farmers compared the bed-and-furrow system with the well-known conventional way of cultivating millet, sorghum and maize: furrows are filled with fertile sediment from upslope farmlands (*shilshalo*, see Nyssen et al., 2011).

Labour benefits recognised in the villages are: (i) easier and faster weeding with less people; (ii) easier and faster ploughing; and (iii) decreased need for oxen. Labour benefits were less mentioned than agronomic benefits; however farmers evaluate the influence of CA upon labour mainly as beneficial. Farmers argue that weeding and harvesting while standing in the furrows is

easier. In addition, ploughing in the furrows demands less intensive power. Similarly, Tesfay Araya et al. (2012) found oven-dried weed weight to be least in CA plots.

In line with earlier findings in the study area, a list of perceived capital (yield) benefits is: (i) a better yield; (ii) larger grains; and (iii) longer and thicker straw. In general, most farmers were positive and state an increase in yield. Some farmers think the yield can increase by half, or can even double. Indeed, according to Govaerts et al. (2005), zero tillage with residue retention results in higher and more stable yields than conventional management, although it can take some years before the benefits are evident. Tesfay Araya et al. (2012) found that soil organic matter and nitrogen losses by runoff were significantly higher in PT compared to CA while phosphorus loss was higher in CA. Although improvements in crop yield were observed, a period of three to five years of cropping is required before they become significant (Govaerts et al., 2005; Tesfay Araya et al., 2012). Also gross margin of the CA practice increased significantly as of 2007 in parallel to crop yield improvement (Tesfay Araya et al., 2012).

3.2.2 High costs for a poor population

All the interviewed farmers in the eleven villages were asked to name all disadvantages they could think of. The most commonly mentioned general costs are: (i) herbicide is expensive and is not effective against some weeds (such as *Cynodon dactylon*); (ii) CA needs more fertilizer than plain tillage because the subsoil is not mixed with topsoil; (iii) the need to leave litter means a loss of livestock fodder (albeit there is some extra fodder production under CA due to a significant yield increase); (iv) CA does not allow to sow sorghum in case of early rains (albeit technically this is possible); and (v) the large furrows limit the area for plants and attract birds that can eat seed. In general, conservation agriculture farmers mention more disadvantages (probably due to their experience with the technique). However benefits are more spontaneously

mentioned than costs. Other mentioned disadvantages are the attraction of mice by straw remaining on the land, the perceived washout of herbicide after a heavy rain, the difficult access to herbicide in Dogua Tembien, and the perceived unsuitability of CA for application in crop rotation. Also, over twenty farmers believed that in dry years the existence of furrows can speed up the drying process, so lower yields (estimated at half of the normal yield) would follow.

3.2.3 Modelling interest in CA

The interest of the farmers in CA could be linked with their perceptions and environment. An analysis of significance and Wald coefficients (Table 3) shows that only the variables ‘benefits’ (number of stated agronomic, labour and capital benefits), ‘costs’ (number of stated costs) and ‘lithology’ (limestone or basalt) contribute significantly to the model. Distance from homestead to farmlands, spatial impedance and knowledge do not contribute significantly to the choice model.

Thus, applying Eq. (4), a farmer’s choice for CA can be modelled as:

TABLE 3

$$\left[\begin{array}{l} \text{CA if } \pi > 0.5 \\ \pi = \frac{1}{1 + e^{-(0.58.b - 0.30.c - 1.03.l)}} \end{array} \right. \quad (5)$$

With b = the total number of mentioned environmental, labour, and capital benefits; c = the total number of mentioned costs; and l = substrate lithology (1 for limestone, 0 for basalt). The model outcome (Eq. 5) shows that the choice for CA is positively dependent on the perception of benefits and negatively dependent on the perception of costs. Farmers in the basalt area are more enthusiastic for the technique than farmers in the limestone area. Indeed, 44% of all farmers in the limestone area are interested in CA, while 55% of all farmers in the basalt area are interested. This binomial logit model (eq. 5) predicts the choice quite well, since 72.2% of the choice is explained (Table 4).

TABLE 4

Finally, the effect of knowledge on interest was assessed. Levels of interest in village x were classified as: (i) full interest without any monetary and other support from the research project (9% of the interviewed farmers); (ii) interest without any monetary support but with technical training (65%); (iii) interest in CA only with monetary support (10%) and (iv) no interest at all (16%). The negative correlation between the knowledge proxy V_x (Table 5) and the indicator of ‘interest if training’ proves that a lack of knowledge leads to a demand for training. However, the more knowledge upon the existence of subsidies for the currently practicing farmers, the more the conventional farmers demand monetary support to possibly join the scheme.

TABLE 5

3.3 Other constraints for the CA acceptance diffusion

Within regional agro-ecosystems, some deeply rooted agricultural traditions persist (Lanckriet et al., 2013). Segers et al. (2010) show how the traditional land rent institution *mwufar* sharecropping persists in the region, despite the emerging land rental market. *Mwufar* consists of a temporary transfer, normally for the duration of one agricultural season, of the use rights on a plot of land in exchange for a share of the grain harvest. Also the traditional informal system of *lefenti*, where a farmer invites friends to help working on his fields, share food and beverages, and later return the favour, persists (Naudts, 2002).

During field work, a multiple ploughing tradition was identified that might slow down the adoption of CA. Two major objections of farmers are: (i) CA fields look weedy (“like rangeland”); because (ii) CA is simply not ploughed enough times. A farmer stated: “*These fields look very ugly, they were not ploughed! I was afraid, did the farmer die?*” A farmer from Gebla Emni (on the other flank of the valley) states: “*the whole village can see these conservation fields. In the dry season it are ugly white spots in Hechi*”. The practice in Tigray in which farmlands that are abandoned for several years are redistributed to landless youngsters contributes to a situation in which it is not wise to have farmland appearing as uncultivated or neglected.

Other farmers explain why they perceive many ploughing operations as necessary. According to the tradition, “*ploughing operations mix the upper (clayey) soil with the (fertile) inner (silty) soil*”. Furthermore, “*the plough would kill soil insects by exposing them to air*” and “*the soil roughness created by the tillage operation would capture the water*”. A farmer states: “*Why would ploughing a lot be wrong? The ancient people did it, so it must be a good technique.*” In contrast to traditional multiple ploughing, a zero-tillage strategy would make “*the soil dry and hard; it would impede the infiltration*”. Even for the typical soil compaction of teff fields, farmers

blame the frequent weeding operations on teff rather than the multiple ploughing tradition. A farmer in Gebela Emni summarizes “*ploughing is for crops like eating for men; you have to do it three times. If not you die*”.

Not only the conventional farmers perceive the reduced tillage as problematic, also the participating conservation farmers have problems with the system. One CA farmer invented a complex trick to fool the programme officers, by temporarily selling his oxen in order to hide to the programme officers his ability to plough a lot (while still he refreshed the furrows of his CA fields three times instead of once with oxen that he hired in).

3.4 Policy recommendations for large-scale implementation

Based on the results from this study, three main conclusions can be drawn (Rec-A, B, C). Future CA adoption schemes should be aware of spatial interferences in knowledge diffusion, take into account the impact of costs-benefit reflections on adoption, and they should allow flexible adaptations of the FAO CA version to regionally varying agro-ecosystems and conditions.

Rec-A. Policy and research should incorporate ‘spatial effects’ in CA adoption schemes.

In many studies, spatial aspects of CA dissemination are not included. However, our study shows the importance of spatial factors and sociospatial networks for knowledge diffusion, which in its turn affects adoption of CA. Therefore, policy-makers must be aware of such spatial interferences if they desire large-scale implementation of CA. For example, the location and visibility of demonstration stations is highly important, at least as much as the ‘social status’ of the demonstration farmers. In this study area, it would for instance have been better to have fewer model farmers in more villages, instead of a lot of ‘model farmers’ in one village (Hechi).

Rec-B. Researchers should incorporate cost-benefit analysis into decision prediction.

CA adoption is often linked with ‘empirical’ household or financial characteristics, or with some biophysical or external factors (Knowler & Bradshaw, 2006). However, although usually based on logit or probit regressions, such a methodology does not take the farmers’ decision process into account, and hence yields inconsistent results over different regions and scientific set-ups. This study shows that the choice of CA adoption depends on the rational comparison of perceived cost and benefits by the farmers, a methodology that could generate more consistent results over different parts of the world. Therefore, incorporating local perceptions on costs and benefits on CA could give better predictions useful for adoption schemes.

Rec-C. Policy-makers should allow adjustments fitting to the regional agro-ecosystem.

Instead of copying the standard FAO CA-model, modifications should allow regional adjustments (FAO, 2010). Incorporating agricultural traditions into future development from the bottom-up is likely more successful than externally imposed technological solutions. Therefore, a CA variant *seleste derdar* is proposed, which would be suitable for short-term large-scale implementation. The Tigrinya word *derdar* appeals to a conventional tillage technique (*derdero* in Amharic) (Nyssen et al., 2011) which we could identify not only in the Amhara region of Ethiopia, but recently also in parts of the Tigray region; hence the use of the locally better understood Tigrinya word *derdar*. *Seleste* is three in Tigrinya and points to the fact that annually (a maximum of) three tillage operations in the furrows fit well with the CA approach as well as with local multiple-ploughing traditions. The variant takes (i) the traditional local practices into account, and (ii) should be implemented with a real bottom-up approach, with farmer-to-farmer extension. Implementation may prove to be beneficial in the protection of local farmers against economic and climatic changes (Lanckriet et al., 2012).

Farmers could carry out CA by refreshing three times in the furrows, albeit without destroying the beds. As some farmers state, they like CA and if refreshing the furrows three times would be allowed, they would participate. Also, though its use definitely decreases weeding drudgery for women and children, herbicide would not be strictly necessary (since ploughing eliminates a large part of the weeds). The bed and furrow system would stay intact, as biophysical evaluation of CA showed that especially the bed-and-furrow system (which causes water ponding) is an important advantage of the technique (Lanckriet et al., 2012). Notably the multiploughing tradition would be respected. Furthermore, repeated refreshing will lead to deeper furrows, increasing the ponding effect. However, before large-scale implementation, we recommend a thorough experimental testing of *seleste derdar*, since the long term goal should eventually be for wider adoption of the *derdero*+ planting system to reduce labour and oxen demand and minimize soil disturbance.

In general, most of the farmers are highly interested in CA-implementation. Notably the CA-ponding effect would be very beneficial, since the biggest group of the farmers in Hechi (43.2%) considers the lack of water for their crops as the main problem of the village; followed by the difficult access to lands for young farmers (27.0%); and access to water for humans and animals (10.8%) (Naudts, 2002). Also the participating conservation farmers are quite interested to continue CA. 33% of the CA farmers state they will continue the project; and 67% claims to continue applying CA but independently from the project (so that “*they can refresh the furrows more than once*”). Large-scale implementation of conservation agriculture could have an important impact on crop production and income. Due to a low marginal product of labor and due to low impacts of fertilizers in this moisture-stressed environment, extension and credit programs have often low impacts on crop yields (Pender & Gebremedhin, 2004). However, these authors

show that crop production and farmers' income in the North Ethiopian Highlands can efficiently increase using low-external input investments and practices such as stone terraces and reduced tillage. This shows the huge agro-economic potential of CA for increasing crop yields in semi-arid regions.

4. CONCLUSIONS

The aim of this study of the Northern Ethiopian Highlands was (i) to reconstruct the diffusion of knowledge on conservation agriculture from the innovation source; and (ii) to reconstruct the acceptance and rejection of CA by conventional farmers. CA was applied both at an experimental station and on nine farmlands in the catchment, and farmers of eleven surrounding villages were interviewed in order to identify their knowledge and acceptance of the technique.

The diffusion of knowledge about the resource-saving technique was conceptualized by the diffusion of innovation paradigm. The CA diffusion from Hechi (the innovation source) is highly dependent on distance, topographic obstacles and visibility towards Hechi. Secondary influences can come from social networks, such as kinship, friendship, church activities, marriage, and administrative boundaries.

Acceptance and rejection of CA was conceptualized on three levels. An analysis of interviews with farmers assessed the perceived benefits and disadvantages of CA. A binomial logit model shows that the choice for CA is positively dependent on the perception of benefits and negatively dependent on the perception of costs. Furthermore, the agricultural tradition of ploughing many times forms an important barrier for CA implementation.

Since most interviewed farmers are in favour of the technique, a new type of CA is proposed for faster implementation in Ethiopia, named *seleste derdar*. With this technique, farmers would

plough up to three times in the furrows without destroying the beds. As some farmers state, they like CA, and if ploughing three times would be allowed, they would participate. Also, no herbicide would be needed (although it would still be possible to use it in order to decrease weeding drudgery), the bed and furrow system would stay intact and the multiploughing tradition would be respected for those who wish. *Seleste derdar* could then be an entry point towards long-term implementation of *derdero*+ (permanent raised bed which has less labour and oxen demand with minimal soil disturbance). Concluding, since the majority of all interviewed farmers evaluate CA quite well, CA can play an important role in future soil-water policy and agricultural intensification in North Ethiopia. Notably under conditions of climate change, CA would prove to be a beneficial actor. Indeed, Deschutter (2010) links CA with both the right to food as to human rights in general: “agro ecology as a mode of agricultural development which not only shows strong conceptual connections with the right to food, but has proven results for fast progress in the concretization of this human right for many vulnerable groups in various countries and environments.”

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Tables

Table 1. Investigated villages, number of interviewed farmers in every village and lithological substrate of the village fields

Village	Interviewed farmers	Lithology
Hechi	11	Limestone + Basalt
May Bati	10	Limestone
Tsigaba	9	Limestone
Hala	11	Limestone
Adi Kalkwal	10	Limestone + Basalt
Upper Harena (Harena Up)	7	Basalt
Lower Harena (Harena Low)	7	Limestone
Dinelet	11	Basalt
Gebba Emni	11	Limestone
Adikwunti	9	Limestone
Khunale	12	Basalt
Total Farmers interviewed	108	

Table 2. Standardized impedance factor I_x as calculated with Eq. (1) using the values d , v and ΔH . d is the walking distance (in km) on footpaths from the village x to Hechi (the innovation source); v is the ‘visibility’ of Hechi from the homestead x (0.5 for visible, 1 for invisible); and ΔH is the absolute height difference (in m) due to ups plus the height difference due to downs between Hechi and village x .

Village	d (km)	v (-)	ΔH (m)	I_x (eq. 1)
Hechi	0	0.5	0	0
May Bati	2.6	1	150.8	0.176
Tsigaba	4.9	1	284.2	0.625
Hala	5.8	1	336.4	0.875
Adi Kalkwal	1.2	0.5	69.6	0.019
Upper Harena	1.9	0.5	110.2	0.047
Lower Harena	1.1	0.5	63.8	0.016
Dinelet	4.0	1	232.0	0.416
Gebba Emni	1.4	0.5	81.2	0.025
Adikwunti	5.6	0.5	324.8	0.408
Khunale	6.2	1	359.6	1.000

Table 3. Factor scores, Wald coefficients and significances of all independent factors of the logit model

Factor	Factor score	Wald coefficient	Significance
Knowledge	0.646	1.565	0.211
Benefits	0.579	9.450	0.002
Costs	-0.295	3.627	0.057
Distance to field	0.011	0.168	0.682
Substrate lithology	-1.033	4.026	0.045
Spatial impedance	0.010	0.208	0.648
Constant	-1.459	2.607	0.106

Table 4. Counts of prediction and observation of choice for CA; as modelled with the logit model. This confusion matrix visualizes the performance of the logit model (predicted classification as compared to observed classification).

	Choose PT (predicted)	Choose CA (predicted)
Choose PT (observed)	39	25
Choose CA (observed)	5	39

Table 5. Interest for implementing CA, as mentioned by conventional farmers (interest without support, under the condition of training, under the condition of a payment; or not interested at all); and Pearson correlation with standardized impedance factor I_x (as calculated with Eq. 1) and the knowledge proxy V_x (as calculated with Eq. 2).

	Interested without support	Interested if training	Interested if payment	Not interested
% of conventional farmers	9.3	64.8	10.2	15.7
Correlation R with I_x	-0.42	0.02	-0.48	-0.08
Correlation R with V_x	0.53	-0.14	0.75	-0.08

Figures

Figure 1. A view of the experimental station, with the village of Hechi visible down in the valley.

Figure 2: Scientific set-up of the study, including the theories, the hypotheses (Hyp-A, B, C), the identified key-determinants of CA adoption and the recommendations (Rec-A, B, C). Arrows represent cause-effect relationships.

Figure 3. Farmer applying CA in his farmland in Zenako. At a distance, the experimental station is visible.

Figure 4. Sampled villages around Hechi and Hagere Selam and location of the study area May-Zegzeg.

Figure 5. Village knowledge score V_x for all eleven villages.