Crop residues tradeoffs in rain-fed areas of Morocco

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Crop residues tradeoffs in rain-fed areas of Morocco

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« On ne doit jamais laisser ces terrains
à l'état de labour (c'est-à-dire à nu) pendant le cours de l'été,
parce que la chaleur du soleil dans cette saison les brûlerait
et les laisserait dépourvus de toute espèce d'humidité
et de graisse et réduits à l'état de poudre »

Ibn Al Awwâm
Agronomist, 12th century

Picture on front page by J. Gauny (Oued Zem region, 2015)

Executive summary

In rain-fed areas of Morocco, integrated crops-livestock systems are put under high stress by erratic climatic circumstances. To reverse the trend of low productivity aggravated by land degradation and drought recurrence, conservation agriculture provides a set of innovative technical options to keep up the yields in a sustainable manner. However, despite positive research outcomes and longstanding efforts to promote it amongst farmers, the adoption rate of conservation agriculture in rain-fed areas of Chaouia-Ouardigha remains low, particularly because the retention of crop residues is problematic to farmers.

This research, undertaken in the frame of a research-action project implemented by ICARDA and INRA-Morocco, investigates the influence of tradeoffs around biomass use on the adoption of cereal residues retention as a soil conservation measure. Tradeoffs are tackled in a systemic approach encompassing agro-ecological, economic, socio-cultural and risk perception-related determinants. Focus group discussions and a household survey as well as a review of conservation agriculture experiments in the area of study underpin the analysis.

The research confirms the existence of a severe tradeoff between competing objectives: the retention of residues for soil cover is not practiced on purpose by farmers, who give priority to livestock feeding and secondarily straw trade. The tradeoff plays out at farm level ("feeding the cow rather than the soil") but also at village scale, as a result of farmers' heterogeneity. Feed alternatives do exist and biophysical advantages of residues retention, proven by research, are generally admitted by farmers, but the short-term horizons of planning hinder uptake by farmers.

Targeting primarily farmers who face moderate tradeoffs (crops-oriented small- to middle-scale farmers in the most homogeneous community), would be a relevant entry gate to dissemination, but a holistic approach including all categories of farmers in a step-by-step process is the best alternative to overcome crucial grazing issues caused by economic and land inequalities.

Keywords: conservation agriculture – crop residues - tradeoffs – adoption – crops-livestock integration – Morocco – rain-fed agriculture – sustainable land management

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Glossary

Adoul	Islamic clerk
Biada	Deep soil, few stones
Bour	Rain-fed land
Fantasia	Traditional horse event
Habous	Religious land
Harch	Stony soil
Makret	Rocky outcrop
Melk	Land ownership
Melk taam	Full ownership
Melk naqqis	Incomplete ownership
Tir	Vertisol

Currencies (as of February 2016)

Euro	US dollar	Moroccan dirham
EUR	USD	MAD
0.91	1.03	10

List of acronyms

ACIAR	Australian Centre for International Agricultural Research
ADA	Agence de Développement Agricole / Agricultural Development Agency
APSIM	Agricultural Production Systems sIMulator
CA	Conservation agriculture
CANA	Conservation Agriculture for North Africa
CBA	Costs-Benefits Analysis
CEC	Cation Exchange Capacity
CF	Crude fiber
CGIAR	Consultative Group on International Agricultural Research
CP	Crude protein
CR	Crop residues
CT	Conventional tillage
FGD	Focus Group Discussion
HAC	Hierarchical Agglomerative Clustering
ICARDA	International Center for Agricultural Research in the Dry Areas
INRA	Institut National de la Recherche Agronomique (Maroc) / National Institute of Agronomic Research (Morocco)
NARES	National Agricultural Research and Extension Systems
NGO	Non-Governmental Organization
NT	No tillage
NT_{50}	No tillage with 50% crop residues retention
PMV	Plan Maroc Vert / Green Morocco Plan
SC	Semis conventionnel / Semis conventionnel
SD	Semis direct / no tillage
SLM	Sustainable Land Management
SOC	Soil Organic Carbon
SOGETA	Société de Gestion des Territoires Agricoles / Agricultural Territories Management Society
SOM	Soil Organic Matter
TLU	Tropical Livestock Unit
WUR	Wageningen University

1. Introduction

1.1 Background and problem statement

1.1.1 Background

The research focuses on rain-fed areas in the region of Chaouia-Ouardigha located in Central Morocco (Figure 1). In these drylands, rural populations are dependent on rain-fed crops and livestock rearing. Both activities are inter-connected and form the core livelihoods of households.

Figure 1 - Chaouia-Ouardigha region, in Morocco (ADA, 2013)

Drylands agriculture

Albeit erratic, rain-fed agriculture is crucial to Morocco, which only meets 62% of its cereals needs (Badraoui et al., 2010). Whereas irrigated lands, which cover 13% of arable lands, are mainly dedicated to high value productions for export (Badraoui et al., 2010), most cereals come from rain-fed areas. Chaouia and Ouardigha contribute greatly to the national production of cereals (Mrabet, 2011), with 15% of the Moroccan wheat being produced in Chaouia (Fredenburg, 2012). Wheat and barley are deemed to be the most significant economic resource in drylands (Mrabet et al., 2012). In these two regions, crops are almost entirely rain-fed, as only 3% of the arable land is irrigated (Agence de Développement Agricole "ADA", 2013). 76% of the arable lands in Chaouia-Ouardigha are used for vegetal production, of which 96% for cereals (ADA, 2013). Livestock consists of small ruminants (mainly sheep) and cattle; and is managed in an extensive way (Mrabet et al., 2012). Land tenure in Chaouia-Ouardigha is characterized by small-scale farms, mostly in full ownership (*melk*): 54.4% of the farms are less than 5 ha and the average size of a farm is 9 ha (ADA, 2013).

Rain-fed agriculture suffers from a number of limitations and constraints, resulting in limited cereal yields (Mrabet et al., 2012). In Chaouia-Ouardigha cereal yields are constrained by the domination of the cereals-cereals rotation and the limited availability of appropriate seeds (ADA, 2013). A number of constraints to livestock production are also identified by the ADA in this region: lack of farmers' knowledge in animal husbandry, crossing of local and improved breeds, inappropriate milk collection technology and inadequate market structure.

Land degradation

Inappropriate land uses and management practices, particularly deep tillage with small hoe cultivators and overgrazing (Mrabet et al., 2012) have led to pronounced land degradation. In Morocco, average erosion rates vary between 2.1 and 20 t/ha/year, yielding a cost exceeding € 1,8 billion per year (Dahan et al., 2012). 53% of the country is affected by water erosion and 17% by wind erosion. At national level, erosion is aggravated by various anthropogenic factors: overgrazing (49%), agricultural activities (24%), deforestation (14%) and over-exploitation of vegetation cover (13%) (Dahan et al., 2012). Dahan et al (2012) acknowledge that conventional tillage, which remains a widespread practice, contributes to annual soil loss.

Climate change

Low productivity and land degradation are exacerbated by new climatic patterns. The region receives 300 to 400 mm per year, with high inter-annual variability though (Mrabet et al., 2011). The decline of annual precipitation is reflected in the reduction of the Length of the Growing Period from 180 to 110 days since the 1980's in Oued Zem region (ICARDA-INRA, Characterization of the Moroccan Platform, 2015). In Morocco, the IPCC predicts a decrease in precipitation by 4% and an increase in temperature between 0.6 and 1.1°C from 2000 to 2020 (Badraoui et al., 2010). "Increased aridity will have negative effects on agricultural yields, especially from 2030 onwards and rain-fed crops (non-irrigated) will be particularly affected by climate change" (Badraoui et al., 2010). Climate change translates into more severe and frequent droughts but also more intense rainfall events resulting in flash floods (Mrabet et al., 2012).

Conservation agriculture: the panacea to dryland agriculture?

To reverse the trend of low productivity aggravated by land degradation and drought recurrence, conservation agriculture (CA) provides a set of innovative technical options (no or minimum till, residues retention and crop rotation) that could help keep up the yields in a sustainable manner. CA is considered one of the most promising options to sustainably improve the productivity of croplands in rain-fed areas (Fredenburg, 2012). Morocco has been a pioneer in experimenting CA, thanks to research institutes such as ICARDA and INRA. CA has been practiced in experimental stations since 1984 and taken to farmers since 1997, starting in Chaouia region (Fredenburg, 2012). However, despite early introduction of CA in the country, the rates of adoption amongst farmers are still very low. According to Fredenburg (2012), only 5,000 ha of arable lands were managed under CA principles in the whole country in 2011. The agro-ecological benefits of CA have been demonstrated through long-term experiments in the stations. Mid-term or long-term experiments (up to 19 years) have shown that grain and fodder yields in plots with no tillage and soil cover are higher than that with conventional tillage and bare soils, in all soil types of Chaouia region (Mrabet et al., 2012; Fredenburg, 2012; Schwilch et al., 2015). While the impact on yields and erosion is clearly demonstrated, some authors believe that CA achieves insufficient socio-economic impacts, due to additional costs of seeder renting and herbicides, and farmers' strategies oriented towards livestock or off-farm activities (Schwilch et al., 2015).

Generally speaking, Morocco is a representative sample of certain failures and disappointments encountered by CA across the world. The early enthusiasm of most researchers and policymakers towards CA has been altered by its low actual dissemination, especially among smallholders in developing countries. While it is believed that CA can effectively work only with the combination of its 3 pillars – tillage, residues and rotation (Schwilch et al., 2015), Giller et al. (2009) affirm that farmers rarely adopt all components. These authors consider that the integrated nature of CA is its main weakness because it implies important simultaneous changes of different practices. Further, adoption of CA practices, whose agro-ecological benefits are sometimes controversial and context-specific, is constrained by the farmers' needs for immediate return to investment. However, many substantial benefits from CA are achieved in the longer term (Giller et al., 2009).

In Morocco, the investment in the mechanized seeder, mainly imported, has been identified as a major constraint to adoption of CA. This is being addressed by ICARDA and INRA in Chaouia-Ouardigha. Further, the retention of crop residues on the surface appears to be another recurrent problematic aspect of CA.

Crop residues retention: the "Achille's heel[1]" of conservation agriculture

Residues are plant materials left in the field after the crop has been harvested. "The residues of cereal crops consist of the stem and some leaf material." (Ben Salem, 2008). In this study, residues include stubble (standing part of the stem) and straw (loose materials of the stem remaining after grain has been removed).

Retaining residues consists of leaving them on the ground after the cereals harvest, by keeping stubble and loose materials from grazing and, in some circumstances, constituting a layer of mulch with these loose materials.

From an agronomic prospective, retaining more crop residues would address some of the limiting factors faced by dryland agriculture in Morocco: water scarcity, Soil Organic Matter shortage, biodiversity decline and erosion. In spite of the potential quick benefits of such a practice on a range of soil and agronomic indicators (Turmel et al., 2015), it poses a problem in terms of its appropriateness in the context of rain-fed areas. Residues are primarily used as feed for livestock and may also be used for other purposes (fuel, construction). In Chaouia, crop residues yield 40 to 50% of livestock feed (Magnan et al., 2010). Therefore, in Moroccan drylands, cereals stubble is a highly valuable resource, especially in dry years and for small-scale farmers (Magnan et al., 2010). This implicit value is correlated to the importance of livestock in the household economies. In rain-fed areas of Chaouia-Ouardigha, livestock rearing is a major income generating activity that determines greatly farmers' strategies. In Moroccan rain-fed areas, farmers are reluctant to change grazing practices because they tend to consider animal husbandry as a first priority (Schwilch et al., 2015). Furthermore, the tension around crop residues is exacerbated by the lack of alternative sources of feed, due to little capacity for growing rain-fed fodder species, reduction of pastures quality (overgrazing) and area (competition with croplands), and reduction of vegetative cover (grasses, shrubs) caused by land degradation in the grazing perimeters surrounding the villages.

The Green Morocco Plan

Some of the structural weaknesses described above are addressed by the national policy framework, which mostly consists of the "Plan Maroc Vert" (PMV), or Green Morocco Plan. This decadal plan launched in 2008 is the cornerstone of the Moroccan strategy towards agriculture and environment. It aims to increase agricultural productivity by modernizing the sector while achieving social impact within the rural population (Badraoui et al., 2010). 40% of Moroccan farms, corresponding to 3 million people, are targeted by this plan. To fulfil these objectives, the PMV promotes the diversification of productions (ADA, 2013), which mainly consists of shifting from cereals to fruit trees (Magnan et al., 2010). Traditional productions, cereals and livestock, are not neglected though. On the contrary, the PMV recommends increasing the cereal production in a decreased area, through sustainable intensification (Mrabet et al., 2012). The PMV recognizes sustainable land management and conservation agriculture practices, such as no or minimum tillage, as methods to achieve sustainable intensification (Mrabet et al., 2012). No till is also a component of the National Plan against Global Warming (Magnan et al., 2012). At this point, it is too early to measure the impact of the PMV; it is not clear either if the PMV addresses the specific issues encountered in the rain-fed areas of Morocco. In addition to the PMV, various laws and policies aiming to conserve and restore degraded lands have been enacted since the 1970's (Dahan et al., 2012). The National Action Plan to Combat Desertification launched in 2001 paved the way towards sustainable resources management (Dahan et al.,

[1] Giller et al., 2009

2012). Nevertheless, the impact of most policies prior to the PMV has been limited, for different reasons: sectorial approaches, lack of management capacity at grassroots level, lack of continuity and consistency in the legal framework, and funding discontinuity (Dahan et al., 2012), contradictory messages about the importance of conventional tillage made by the Ministry of Agriculture (personal discussion with O. El Gharras, 2015).

1.1.2 Problem statement

Despite positive outcomes of multiple experiments and longstanding efforts to promote it amongst farmers, conservation agriculture has been adopted by a minority of farmers in rain-fed areas of Chaouia-Ouardigha. Different constraints and drawbacks hinder the adoption of conservation agriculture. Among these, the adoption of crop residues retention as a soil cover technology for improving crop productivity is a thorny issue for farmers. Farmers' decision to not retain residues is driven by tradeoffs which are known to be particularly acute in small-scale farms, where crop production and livestock are integrated and contribute equally to the household economy. These tradeoffs are determined by a number of factors which have to be better known in order to bring tailored solutions to the farmers.

1.2 Conceptual framework

1.2.1 Approach

The research is embedded in a conceptual framework which is structured around the analysis of tradeoffs between different crop residues uses.

The tradeoffs analysis has become more and more popular in the field of agricultural studies since the 2000's (Klapwijk et al., 2014). According to Klapwijk et al. (2014), tradeoffs encompass "exchanges that occur as compromises". It can for instance reflect choices made by farmers between meat and milk production, or between different crops. It supposes that synergies, the opposite of tradeoffs, are not always reached; in other words, farmers have to engage in strategies or practices at the expense of other ones. Klapwijk et al. (2014) note that tradeoffs are more acute when resources are constrained. There is a close relation between tradeoffs (or absence of synergies) and farming system intensity. In this regard, the tradeoff analysis approach is particularly effective to characterize less intensive rain-fed systems. These stressed agro-ecological systems leave farmers with tradeoffs often involving critical compromises between natural resources and economic security.

In rain-fed areas, due to the scarcity of natural resources, small-scale crops-livestock systems face crucial tradeoffs around crop residue biomass use. Looking at the bottlenecks and limits in the adoption of sustainable land management measures, which have also shaken the expected success story of conservation agriculture, scientists have recently put a fresh emphasis on tradeoffs inherent in the integrated nature of crops and livestock systems in many developing countries. These biomass tradeoffs can be illustrated in a simplistic manner through the dilemma between "feeding the soil or feeding the cow" (Tittonell et al., 2015). Leaving crop residues after the harvest as a soil amendment practice is a component of conservation agriculture. However residues also are a major source of feed for livestock and can be used for other purposes (e.g. fuel). Hence potentially contradicting objectives may conflict. Tittonell et al. (2015) identify three degrees in the severity of tradeoffs between two competing objectives (e.g. feed and soil amendment): complementarity (both objectives are achievable within a wide range of possibilities), substitutability (an objective can be proportionally replaced by the other one and vice-versa) and competition (severe tradeoff, strong competition between the two objectives). In addition, central is the role of temporality in the appreciation of tradeoffs (Erenstein, 2015): short-term competition between soil amendment and livestock feed may turn into synergies on the longer term, if soil amendment improves feed production (Tittonell et al., 2015).

The tradeoffs around biomass use constitute an inter-disciplinary approach which embraces the agro-ecological, economic and socio-cultural valuation of crops residues retention as a conservation measure. It offers a relevant spectrum to grasp the complexity of farmers' decision making drivers.

This theoretical approach fits the objectives of the present research. In Moroccan drylands biomass production is erratic while crops and livestock production systems are tangled. As a result, the crop residues use gives rise to tradeoffs which mainly translate into competition and may perpetuate livelihoods insecurity, land degradation and vulnerability to climate change. Looking at a site-specific case study through the tradeoff lens is appropriate since many authors have recently come to conclusions that the prevailing mechanisms around residues use are hardly universal as they depend on variable local factors (Tittonell et al., 2015). Thresholds of complementarity, substitutability and competition are highly sensitive to context-specific parameters such as the agro-ecological potential, markets, land availability and farming systems (Tittonell et al., 2015). This research aims at characterizing the severity of residues tradeoffs for Moroccan farmers, as well as the parameters enabling to go towards more substitutability or complementarity.

1.2.2 Concepts

This study is at the convergence of the land degradation (from a people prospective) and sustainable land management (from a practices prospective) spheres of interest.

More specifically, the tradeoff analysis approach deals with a number of concepts which are described in this part. These concepts reflect the driving forces or determinants of tradeoffs around crops residues use, which ultimately influence the adoption of a given best practice by farmers (Figure 2). Three major determinants are described: the agro-ecological impact of crop residues (especially on yields), the economic profitability of different crop residues uses, and the socio-cultural circumstances of the farmers. The temporal dimension of tradeoffs, or how farmers deal with risks over different time horizons, is considered in this study another transversal factor of tradeoff.

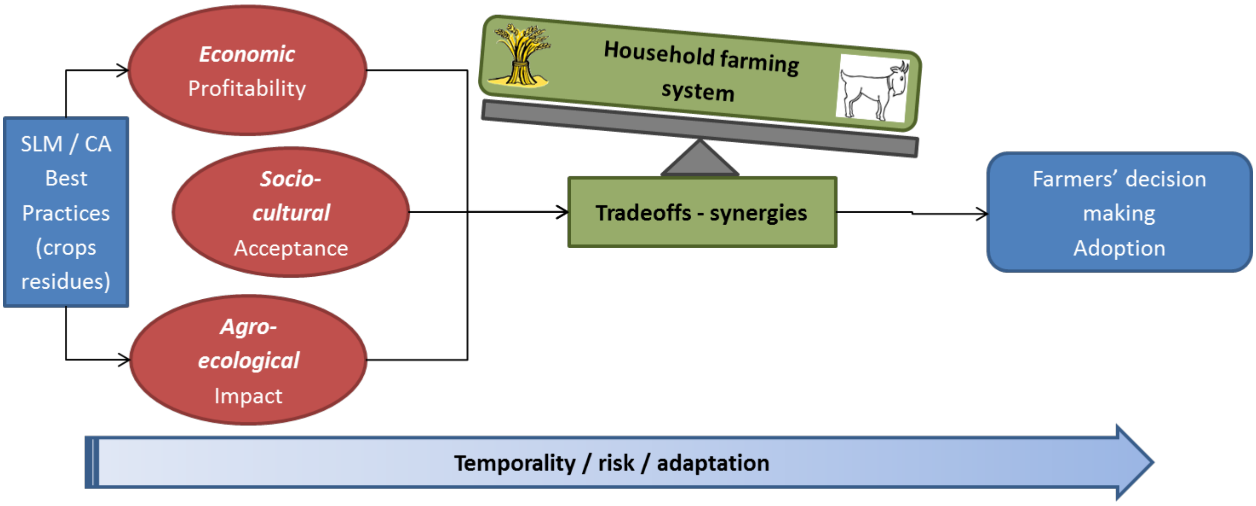

Figure 2 - Conceptual framework

Best practices

Best practices in sustainable land management are built around three principles: increasing productivity, improving livelihoods and improving ecosystems (Liniger et al., 2011). Under this definition and from an agronomic point of view, the retention of crops residues as a soil cover is considered a best practice. However, the low rates of adoption of this measure in rain-fed areas of Moroco show that the retention of crop residues is not perceived by the farmers to be good enough to significantly improve their livelihoods.

It indirectly raises the question of the success factors of conservation agriculture, as a full package or as a set of tailored options (Pannell et al., 2014). Ultimately, we want to know how "best" and susceptible to be adopted the recommended practices are, in a specific context.

Agro-ecological impact

We use the concept of impact to tackle the influence of new SLM practices, i.e. crop residues retention, on agronomic and environmental features. Agronomic (increased yields) and environmental (decreased land degradation) impacts of practices or technologies are a key determinant of tradeoffs and adoption (Tittonell et al., 2015). Expected beneficial impacts of residues cover are multiple: increased soil moisture, decreased water erosion, protection against wind erosion, enhanced organic matter and biological activity, moderated soil temperatures (Thierfelder and Wall, 2008). However, these benefits may be impaired by drawbacks (weeds, reduced animal manuring). This research focuses only on onsite impacts, ignoring effects of crop residues management on downstream areas (e.g. sedimentation, flooding risk). Since crop residues retention is an innovative technology in the area of study, attention is mainly given to potential impact, possibly correlated to impact observed by the early adopters.

Impact can be appraised through different time scales, which is a core factor of tradeoff analysis as variable impacts at various time horizons influence farmers' decision making. Nonetheless, impact is considered positive only if durable. In this sense, impact assessment also is a measurement of sustainability. Impact assessment supposes quantification and use of indicators, so as to compare with the effects of a measure to other or no measures.

Economic profitability

De Graaff et al (2008) consider profitability as a requirement for continued use, that is to say adoption, of an innovative technology. Pannell et al (2014) underline the importance of economic drivers at farm level in the adoption of conservation agriculture. The understanding of the household economy is a prerequisite to biomass tradeoffs analysis. The relative characteristics and weights of cropping and livestock systems in the household economy prefigure farmers' preferences and potential economic impacts of crops residues management. Any tradeoff between different options influences the equilibrium of crops and livestock systems and ultimately, the household economy. Even though farmers' choices are not always rational (Pannell et al., 2014), tradeoffs reflect to some extent a cost-benefits analysis made by the farmer, which incorporate immediate and opportunity costs and expected returns. The notion of opportunity costs is adapted to the crops residues case, as residues have a non-cash value for feeding livestock or other uses (Pannell et al., 2014). The profitability of different alternatives is also determined by the given market context and the available resources (land, alternative fertilizing methods, alternative biomass and fodder resources).

Acceptance

Another driving force of the biomass use tradeoffs takes on socio-cultural aspects. Acceptance is the first necessary step in the adoption process (de Graaff et al., 2008). It describes the farmers' perception of land degradation symptoms and drivers (anthropogenic in particular), and the relevance of the proposed alternatives to reverse this process. In the end, perceptions and values may erect barriers to the adoption of land use practices which promise to achieve profitable and environmentally sustainable impact. Studies have proven that acceptance of land management issues and willingness to sustainably change behaviors are bound to social capital (Pretty, 2003), whose different facets, such as reciprocity, connectedness in networks and existence of common rules, deserve to be touched on.

Decision-making and adoption

Biomass tradeoffs lead to decisions made by farmers. These can translate into the adoption of SLM or CA measures in relation to crops residues retention. Adoption suggests continued use (de Graaff et al., 2008) that we cannot assess during the lifespan of this study. Therefore, we characterize the potential for adoption of crops residues retention, based on the key determinants described in this conceptual framework (agro-ecological impact, economic profitability, socio-cultural circumstances, risk aversion and temporality).

Temporality

Temporal dimensions of crop residues tradeoffs tend to be underestimated (Tittonell et al., 2015). Erenstein (2015) states that the challenge in biomass uses lies in the fact that crops and livestock combine different temporal dimensions. Farmers often face conflicting choices between short term needs (e.g. feeding livestock, possibly at the expense of crops productivity and soils health) and long term change (e.g. enhancing the productivity and sustainability of the crops systems, that might entail immediate feed shortages). Moreover, time plays out a role in the valuation of economic returns (discount factor). Temporal scales should also be taken into consideration to comprehend seasonality as a factor guiding biomass tradeoffs.

The multiple temporal dimensions of economic and agronomic costs and benefits contribute to explaining how slow the process of adoption of conservation agriculture in developing countries' drylands is (Pannell et al., 2014). However, Pannell et al. (2014) stress that mulching brings both short term (increase in soil moisture) and longer term (soil fertility) effects. Tittonell et al. (2015) argue that synergies may be found on the long term, when a sound increase in crops productivity thanks to SLM measures also contributes to improving livestock productivity.

The importance of time horizons in biomass use tradeoffs implies some degree of uncertainty that farmers have to deal with. Uncertainty may be aggravated by the lack of knowledge of or confidence in the performances of a practice (Pannell et al., 2014). How farmers cope with uncertainty is narrowly connected to a certain "culture of risk". Poor small-scale farmers are known to be highly risk-averse (Pannell et al., 2014). In the end, the risk aversion of the farmer determines his planning horizon. Understanding the factors of uncertainty over different time horizons and the risk aversion of farmers will/can greatly help grasp tradeoffs around SLM or CA practices and potential adoption of these.

In addition, understanding temporality as a tradeoff determinant allows tackling the adaptive capacity of farmers. Tradeoffs analysis may give a hint of signs of anticipatory or passive adaptation, or increased vulnerability on the contrary. In this research, we investigate to what extent tradeoffs between residues uses reflect an adaptation to long term climate change and specifically to droughts unpredictability and recurrence.

All in all, integrating temporal scales in the conceptual framework brings an additional prospective to the tradeoffs factors (agro-ecological, economic and socio-cultural) and allows getting closer to the understanding of the farmers' decision-making process.

1.3 Research

1.3.1 Research objectives

The broader goal of this research lies in the identification of promising sustainable land management measures in relation to agriculture in drylands, within a prospective of improved environment and livelihoods. More specifically, this research focuses on the appropriateness of the use of post-harvest crop residues as a conservation measure, exploring mostly the socio-economic aspects. Through this particular lens, we aim to tackle farmers' tradeoffs with respect to biomass management for competing purposes (crop productivity, feed, trade). In this regard, this research identifies with the field of crop residues tradeoffs analyzes.

To understand the low adoption of crop residues retention as a soil conservation measure, this study aims to document crop residues tradeoffs at farm level, through the lens of factors determining these tradeoffs and farmers' decisions, over different time horizons. The expected output of this study is to establish a farmers' typology, with regard to the severity of their tradeoffs and the factors of crop residues use.

The integration of agro-ecological and socio-economic considerations to characterize the suitability and potential for adoption of specific SLM measures constitutes the core of this research, which hence aims to strong interdisciplinarity.

1.3.2 Main research question

The main research question is delineated as follows:

In the context of rain-fed areas of Chaouia-Ouardigha (Morocco), how do tradeoffs around biomass use influence the adoption of crop residues retention as a soil conservation measure?

1.3.3 Sub research questions

Five sub-research questions are formulated:

i. What are the current characteristics and history of crop residues management?
ii. What are the potential agro-ecological on-site benefits and drawbacks of crop residues use as soil cover?
iii. How are the equilibria and profitability of household production systems, especially livestock, altered by the adoption of crops residues retention?
iv. How do the farmers' perception of and experience with conservation agriculture and land rights shape potential decision to invest in crop residues retention?
v. To what extent do the farmers' risk aversion and temporal dimensions of costs-benefits influence the adoption of crop residues retention as a soil conservation measure?

1.4 Context of the research

1.4.1 The CANA project

This thesis was hosted by two organizations in Morocco: ICARDA (International Center for Agricultural Research in the Dry Areas, CGIAR affiliate) and INRA (Institut National de Recherche Agronomique, National Institute of Agronomic Research, Morocco). These two organizations have a longstanding experience in implementing joint research projects about drylands agriculture in Chaouia-Ouardigha region.

The research built on the learnings from the programme "Adapting conservation agriculture for rapid adoption by smallholder farmers in North Africa" (CANA) funded by the Australian government (ACIAR, Australian Centre for International Agricultural Research) and implemented by ICARDA along with INRA between 2012 and 2015. This programme aimed to introduce two communities of Oued Zem region to conservation agriculture. Oued Zem is a city located in the former Khouribga region (now part of the Chaouia-Ouardigha region). The communities, Beni Khirane and Smaala, are defined as tribal territories inherited from pre-independence times. This was the first attempt to promote conservation agriculture in this area.

The CANA project, which was also implemented in Algeria and Tunisia, was articulated around three core objectives:

i. "To identify constraints to adoption of CA by smallholder farmers and ways of enhancing adoption, most importantly identifying and testing socioeconomic options";
ii. "To identify and test improvement in seeding machinery, and in weed and biomass management of CA systems";
iii. "To enhance the capacity of NARES [*National Agricultural Research and Extension Systems*] staff and other stakeholders to practice and promote CA".

The project was research & action oriented, the researchers being themselves deeply involved in practical activities with farmers. The project was to follow a gradual pathway allowing the scaling-out of best practices demonstrated by research. The Moroccan innovation platform was structured around three levels of implementation: 10 farmers involved in the identification of promising options after research-managed trials; 20 additional farmers involved in the confirmation of these options after farmer-managed trials; and 500 farmers targeted for dissemination. The scaling-out strategy was ensured by a stakeholder created by the project, an association of CA farmers involved in the trials. Al Baraka, the association created at the beginning of the project under the umbrella of a national NGO (Agenda), became a key actor at the interface between researchers and farmers.

In practical terms, the project was very much focused on the first pillar of conservation agriculture, no tillage ("semis direct"). It emphasized a lot on the development of a no-till seed drill (CANA Final Report, 2015). Under the second objective, though, some efforts were dedicated to "optimizing crop residue management and livestock feeding under CA systems" (sub-objective 2.3). If the development and testing of alternative feeding options translated into research- and farmer-managed trials of forage mixtures, the activity "Technical and economic assessment of tradeoff between surface cover and animal productivity" was under-achieved, showing the sensitivity of biomass management in this context. Trials with different crop residue management treatments were undertaken on an experimental station. However, adverse climatic conditions and the unexpected shortening of the project, as well as problems in the research protocol, hampered the research team to draw scientific conclusions from this experiment. In the end, crop residue management was not tested by farmers themselves, and remained limitedly tackled in sessions of farmers' capacity building. As a result, the present study on crop residues tradeoffs is intended to fill a knowledge gap and directly contributes to an initial learning objective of the research project.

1.4.2 Description of the area of study

The area of study is located in Oued Zem region, in the North-Eastern part of the Chaouia-Ouardigha province. Most villages of Smaala and Beni Khirane communities are found near the road from Oued Zem to Rabat. Kasbah Trosh and Ouled Fenane are the most important villages in Smaala area; Ouled Boughadi is the administrative center of Beni Khirane area (Figure 3).

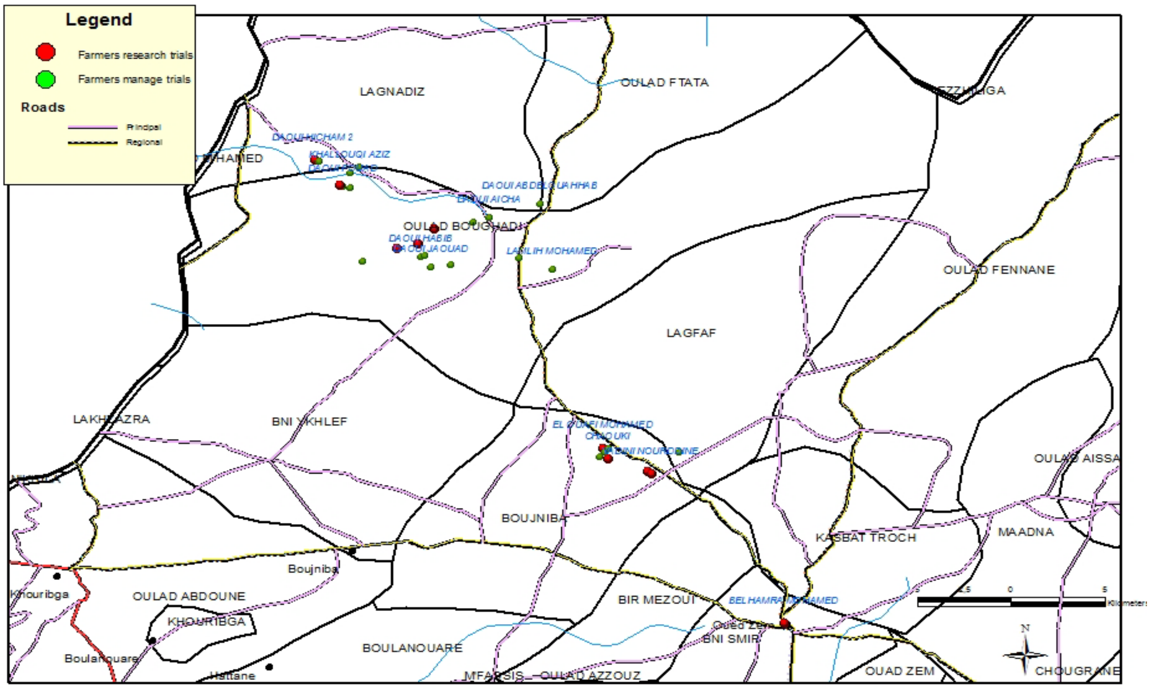

Figure 3 - Map of the area of study (INRA, 2013)

Smaala and Beni Khirane areas are located at the Northern edge of the phosphate plateau (between 800 and 950 m). The topography consists of flat areas surrounded by gentle-slope hills topped by stony outcrops (*makret*). In the farmers' semantics, soils types are determined by topographic features and the degree of stoniness. *Harch* describe stony degraded soils located on slopes; *biada* correspond to deeper soils in flat or gently undulating areas, with low density of stones. Rain-fed agriculture is practiced on both types of soils, with better yields on *biada*. Small-scale irrigation is practiced in some areas with *biada* soils. *Biada* soils are principally found along the axis from Oued Zem to Ouled Boughadi, in Smaala community (Kasbat Trosh commune).

The climate is semi-arid with tempered winters (Boulal, 2001), with an average of 306 mm from 1980 to 2012. Mean annual temperatures are generally about 10°C for the coldest month and 25°C for the hottest month. 70% of precipitations occur in autumn and winter (ICARDA-INRA, Characterization of the Moroccan Platform, 2015). Since the 1970's the region witnessed a significant reduction of annual rainfall while inter-annual variability remains pronounced (Figure 4).

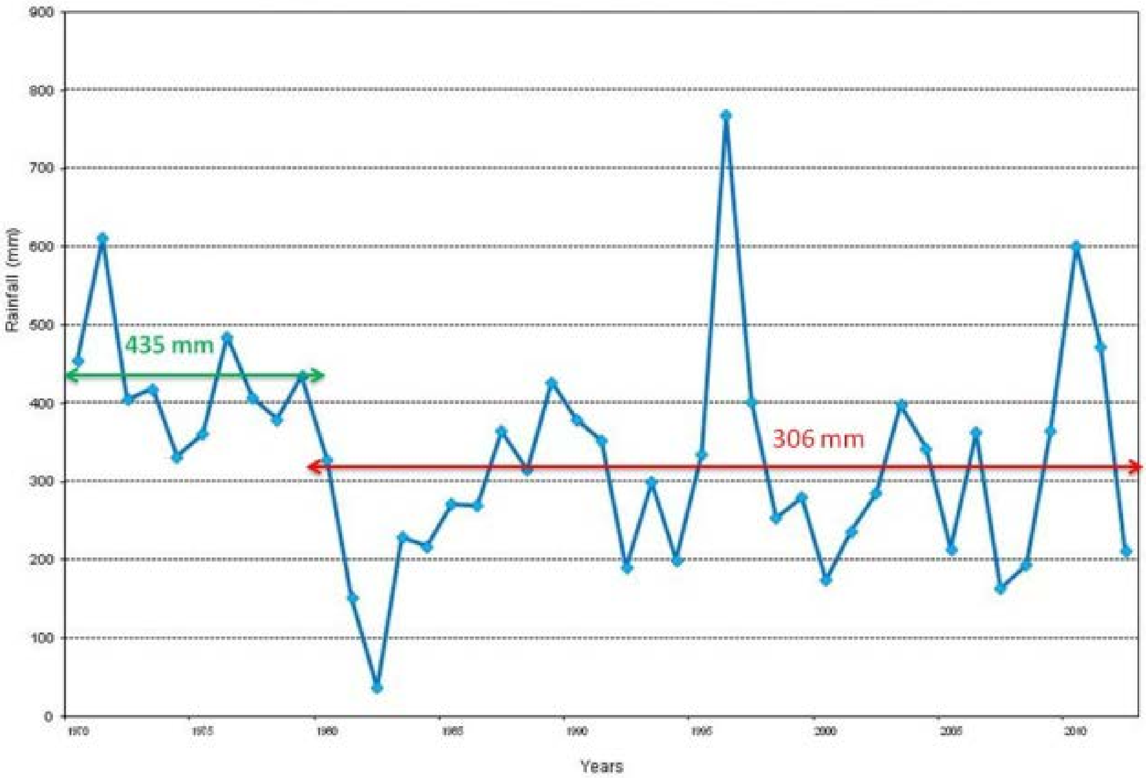

Figure 4 - Mean annual rainfall from 1970 to 2012 (ICARDA-INRA, Characterization of the Moroccan Platform, 2015)

Photo 1 - Landscape in Beni Khirane area (Gauny, 2015)

2. Methodology

This work relied on a literature review (contextual and thematic), focus group discussions and a household survey.

2.1 Background literature and visits

2.1.1 Academic literature

The academic literature review covered different topics:

- Conservation agriculture, including biophysical effects of crop residues retention
- Crop residues tradeoffs. The publication early 2015 of a dozen of articles in a volume of Agricultural Systems (134) offered a comprehensive overview and a helpful guidance on this topic.
- Agricultural context in Morocco (conservation agriculture, land tenure issues, policies, feeding systems, crop residues use, land degradation)
- Adoption of conservation measures
- Crop-livestock systems
- Risk aversion, perception and management

2.1.2 Project literature

Different documents pertaining to the ICARDA-coordinated CANA project were made accessible by INRA. These documents haven't been published, even though some have fuelled academic publications. The present study builds on learnings described in the following documents:

- CANA proposal (2011)
- CANA final report (2015)
- Characterization of the Moroccan platform (2015)
- Adoption of No-Till system (2015)
- Economic evaluation of No-Till technology (2015)
- Optimizing management of crop residue (2015, partial results, not for publishing)
- Baseline survey database (2013)

In addition, this documentation was completed with individual conversations with INRA researchers: Oussama El Gharras (CANA coordinator in Morocco), Mohamed Boughlala (socio-economic aspects) and Mohamed El Koudrim (livestock aspects).

2.1.3 Field visit and *ad hoc* exchanges

A field visit was organized in September alongside INRA researchers. *Ad hoc* discussions with local farmers were done. Furthermore, we had an open discussion with Hicham Daoui (president of the association promoting no-till) on crop residues use and grazing issues.

2.2 Focus group discussions

Two focus group discussions (FGD) were organized in each community, on October 3rd (Beni Khirane) and 4th (Smaala). These consisted of two parts: a participatory timeline exercise and a semi-open discussion on crop residues' management. The first one took place in the morning, followed by the second one. Each discussion lasted between 1h30 and 2 hours. The FGD were co-animated by 2 INRA researchers (Oussama El Gharras and Mohamed El Koudrim).

2.2.1 Overview

The number and profile of participants were difficult to fully control, since the practical organization of the meeting was delegated to the CANA focal point in each community. Although some recommendations were given, so as to have a representative picture of the farmers' diversity, these were limitedly put into practice. Smallholders with important livestock were particularly under-represented. The instruction of discussing the timeline with few elders was respected, even though the participation to the two exercises was finally mixed up, with few farmers arriving and leaving at any time.

However, these focus group discussions allowed a quite active participation of the farmers invited, who released a substantial amount of valuable information. Different voices were heard, although, as often happens with this type of event, some opinions were more dominantly voiced. The participants reached consensus on most answers. Both exercises brought some keys for better understanding and interpreting data from the household survey.

2.2.2 Timeline FGD

Form in Annex I

The main goal of the timeline FGD was to grasp and visualize trends and changes in climatic patterns, land use and agricultural practices in the last decades; and to stimulate discussion on how and why practices, especially with regards to crop residues, changed. A list of topics was used to structure the discussion (Table 1). Information was reported on a flipchart picturing a chronogram from the 1920's to nowadays, developed into several topics.

Table 1 - Topics explored in the timeline

Topics
Severity and frequency of droughts (distinguish "drought", "normal" and "good" years)
Land use changes (croplands, pastoralism, natural vegetation / forest)
Land rights and grazing evolution (from local farmers and external herders, history of disputes)
Crops management: species, tillage (draught animals, machinery, no or minimum till)
Crop residues use (rough proportions: feed, soil cover or other; distinction straw / stubble; removal techniques)
Livestock feeding : type (grazing vs stall feeding, forage, by-products) and calendar
Cereals grain and residues yields (rough estimate)
Farmers' organization
Demographic / migration trends

Detailed and consistent trends, consisting of steps and milestones, were highlighted. The farmers proved to be conscious of why changes occurred, what the effects of these changes were and how they related to one another.

2.2.3 Crop residues' use FGD

Form in Annex II

More farmers (~ 10) were invited to participate to the FGD about crop residues' use. This discussion aimed to get a general picture of what land use practices are, how crop residues are used and what the rationale behind choices is. The following topics were tackled: current crop residues' uses; land and grazing rights; livestock feeding; conservation agriculture; socio-cultural aspects; drought; time preferences & strategies. Quantitative figures (e.g. yields, straw price) were reported on a flipchart, with a comparison between the 3 types of year (normal, good, dry).

A list of open questions had been prepared but proved to be difficult to follow, due to the number and length of participants' interventions. As a result, a number of questions were not tackled at all, albeit touched upon through other questions. Furthermore, the question of unauthorized grazing issues appeared to be sensitive. Statements on this matter were quite confused and not totally consistent with what farmers said in private before the FGD or during the household survey. Although no smallholders engaging in unauthorized grazing attended the session, land owners seemed to refrain from complaining about this issue in public.

2.3 Household survey

2.3.1 Objectives and design

A survey was carried out in order to collect quantitative data at household level. Questions referred to 10 topics: "farmer information"; "agricultural overview"; "agricultural productivity"; "crop residues production"; "crop residues use"; "importance of livestock"; "livestock feeding"; "attitude towards conservation agriculture"; "land and grazing issues"; and "risks perception". Every question was coded and called for an answer consisting of either a choice among proposed answers (to be ticked) or a figure (e.g. production, price).

Form in Annex III

2.3.2 Sampling and implementation

The farm was the unit of analysis. All the respondents were farmers and cultivated cereals in rain-fed lands.

The sample size was principally limited by the number of enumerators. I led all the interviews myself, with the assistance of M. Hassani (INRA technician) for facilitation and translations (from Darija to French). Two interviews could be done in French. Moreover, as the survey was conducted in the second half of October, most farmers were getting ready to prepare the land for sowing. In consequence, it would have been harder to find farmers available if the survey had been prolonged. Lastly, due to the impossibility to reach a statistically representative sample of the population, for the reasons explained above, priority was given to the quality of interviews rather than their number.

In total, 40 households were surveyed, which corresponds to the minimum sample that was expected before the survey. Based on the 2014 census, 5,832 households live in the two targeted communities, distributed in 4 communes: 1 commune in Beni Khirane community (Ouled Boughadi); 3 communes in Smaala community (Kasbah Trosh, Maadna and Ouled Fenane). Although the survey encompassed only 0.7% of the total number of households, it is to be noted that all households do not have rain-fed farms, which increases the actual percentage of households included in the survey. Despite the largeness of the population, we decided to include the two communities in the survey because, first, these two were part of the CANA project, and second, given their respective characteristics, we expected interesting differences in terms of crop residues patterns.

In order to minimize the risks related to the small size of the sample, we used a quota sampling method. Other sampling methods were not satisfactory, as the sample was too small to establish relevant strata and the limited number of respondents made it risky in terms of representativeness to use solely a random sampling. The quota sampling consists of determining a minimum and maximum number of respondents meeting some pre-defined criteria. The sample is then built on the basis of the distribution of these criteria across the population. The selection of criteria and thresholds of distribution in the population is judgmental. In this study, it was mainly based on the baseline survey of the CANA project (2013). Three criteria were selected (Table 2): the adoption of no-till; the cropland area; and the flock size. Assuming that adoption of no-till is a prerequisite and a first step in the process of adoption of crop residues as a soil conservation measure, it was believed that the adoption potential of crop residues retention would be higher for those who have shown a positive attitude towards no till. Furthermore, the relative importance of crops and livestock in the household economy, expressed in the two other criteria, was assumed in this research to be a key determinant of the crop residues tradeoffs. Ensuring the participation of different profiles of households (basically, those who are more herders and those who are more farmers) to the survey was crucial to bring out how differentiated and inherent in the household livelihoods these tradeoffs are.

Table 2 - Sample criteria and quotas

Criterion	Population	Data available	Quota (min-max)	Survey
No-till adoption	Farmers involved in trials (CANA)	45% of 30 trials farmers[1]	2-3	6
	Farmers who dropped trials (CANA)	55% of 30 trials farmers[1]	3-4	1
	Spontaneous NT adopters	No data	1-2	4
	Conventional tillage	88%[1]	32-36	29
Cropland area	< 10 ha	41.7%[1]	14-18	16
	> 10 ha	58.3%[1]	22-26	24
Flock size	< 20 sheep	44.6%[1]	15-20	18
	> 20 sheep	55.4%[1]	20-25	22
Community	Smaala	4,189 households[2]	22-25	23
	Beni Khirane	1,643 households[2]	15-18	17

[1] INRA data (Baseline survey, 2013; CANA final report, 2015); [2] Population census 2014 (http://rgph2014.hcp.ma/downloads/Publications-RGPH-2014_t18649.html)

List of respondents in Annex IV

Most interviewees were referred to us by the focal points of the CANA project. Statistics about interviewees' characteristics were updated every day so as to ensure that the sample would stay within the boundaries of the agreed quotas. Hence, criteria defining the desired characteristics of interviewees were communicated to the project' focal points on a day-to-day basis. At the end of the survey, we can acknowledge that quotas have been overall respected (Table 2), despite a slight inflation of no-till adopters which is explained by the fact that our focal points were themselves no-till adopters, hence tended to present farmers of their own network.

The interviews took place in various places (farmer's place, cooperative, public places ...). Each interview lasted between 45 and 75 minutes, mostly depending on the importance and diversity of crops and livestock for the respondent.

2.3.3 Limitations

Even though the outcome is satisfactory with regards to the objectives, a number of limitations were encountered during the survey, which finally altered the quality of information. The absence of total control over the interviewees' characteristics, depicted in the previous paragraphs, is one of these limitations. In addition to this, the circumstances of the data collection may have hindered the quality and precision of answers. As interviews were rarely done in private closed places, with a strict schedule, a number of interviewees were distracted or could be influenced by other people present during the interview (often, the farmers waiting to be interviewed later on). Given the duration of the interview and the details needed, it has been sometimes hard for the interviewees to maintain their focus after the first 30 minutes. It resulted in a certain loss of accuracy and subtlety in the answers. Furthermore, the lack of precision in translation was another hindrance, especially to precisely express the essence of the questions and to report the nuances of the answers. Answers were rather interpreted than exactly translated, which has some advantages (e.g. transcription of what the farmer says with his own words or vision) but may create a bias. This bias may have been reinforced by the repetitive nature of the survey, once the translator has developed his own understanding of the questions and possible answers, after several interviews. It had been suggested to use cards, with answers written on them, for questions involving a choice or a ranking of options or constraints. This was finally not done, due to the fact that a number of farmers could not read these cards. Therefore, flexibility was required so a pinch of adaptation of the questions was brought to the way the questions were phrased. For example, in the question referring to decision-making factors (8.10), instead of enumerating all the possible factors in an abstract manner, we tried to refer to specific practices already mentioned and investigate the rationale behind these practices. In the case of this question, if a farmer mentioned that he uses to burn stubble, we would then formulate the question "for what reasons do you burn stubble, does it come from your father, or a personal experience, or are you persuaded that it will increase the yield", instead of asking the question as worded in the questionnaire ("What are the two more important factors that influence your own decision to use a specific farming practice?", with 11 possible answers). Further to this, for this kind of question leading to a choice amongst coded answers, we tried as much as possible to first leave the floor to spontaneous answers (that would be then allocated to the coded answers), and then, to suggest possible answers. The risk of the latter is to have too much influence on the interviewee's thinking.

Questions susceptible to entail confused or irrelevant answers are listed in Table 3. Few of these questions have been ruled out of the analysis in this report, whereas for most of them, results will be presented with caution, provided the remarks below are borne in mind.

Table 3 - Synthesis of questions susceptible to confused and imperfect answers

Question	Remark
2.6 What are your land rights over this land?	The distinction between fully private lands and formerly individualized collective lands was not always clear
3.1, 3.2, 3.3, 4.1, 4.2, 4.3 Cereals' grain and straw yield	The distinction between normal, good and dry years was clear to the interviewees, but they may have over- or under-estimated good and dry years while referring to the best/worst case scenarios, although we asked as much as possible to look backwards into the last 3 years (2012-13 was "good", 2013-14 was "dry", 2014-15 was "normal", according to INRA researchers)
4.5 How much stubble do you produce? (equivalent days of grazing for a 20-sheep flock)	Due to potential confusions on the spatial unit (ha or whole farm) and stocking rate (20-sheep flock or total household livestock), answers must be taken with a pinch of salt
5.1 What degree of control over your crop residues do you think you have?	The notion of "control" was quite difficult to reflect in local language. Illustrating the question with examples of lack of control (e.g. unauthorized grazing, machinery flaws) has probably biased the answers.
5.2, 5.3 Out of 10 units of straw/stubble, how much do you use for (different functions)?	The estimates of straw and stubble uses are often approximate. The actual quantity of stubble left on the soil is probably under-estimated (developed in the "Results" section). The amount of straw left on soil may be confused with stubble. A marginal part of residues is used for bedding and roofing, but this has never been explicitly reported by interviewees. Knowing roughly what parts are grazed by the respondent's livestock or by a neighbor's flock proved to be hardly possible.
6.1 What do you perceive as most important [between crops and livestock]?	The notion of "importance" doesn't refer only to direct incomes, but includes the indirect (e.g. crop production ultimately serves livestock production) and cultural (e.g. pride of owning livestock) value of these two components of the farming system. However, this subtlety wasn't easy to explain to the interviewees.
6.5 How many cows do you have?	It was necessary to then separate milk cows and fattened calves.
6.8 Even with feed changes, do you notice an increase in the livestock mortality rates in dry years?	The question, when asked, explicitly referred to young animals
7.1 to 7.14 Feed calendar	Two elements are asked: the type of feed per animal and the

	duration. The content of rations, which varies according to the type of animal and risk of drought, is not reflected in this part. Feed quantities were the object of holistic questions (total quantity needed for different types of feed in one year), in 7.15
7.22 What is the main advantage of cereal residues as feed?	This question was not well understood by the respondents. Hence the results take a minor place in the analysis.
8.4 Do you have experience with purposely keeping more residues on croplands after harvest?	Surprisingly, quite an important part of the respondents asserted having experimented once higher crop residues retention. When we asked for more details about the reasons or the results, the explanations were more confused. Therefore, the answers to this question must be looked at with caution.
8.5 Which of the following statements referring to potential benefits of maintaining more residues do you agree with?	It seems that most farmers did not understand the 2 statements referring to the fact that retaining more residues (by stopping stubble plowing or straw baling) would decrease the costs involved by the non-retention.
8.6 Which of the following statements referring to potential shortcomings of maintaining more residues do you agree with?	Some statements were apparently not fully understood by the respondents, despite efforts to rephrase them: “There is no realistic feed alternative to residues”; “Without residues grazing, there is no animal manure supply”; “Whatever the benefits, the economic value of straw is too high”
8.7 In case you retain more cereal residues on the soil, what maximum percentage of retention would seem acceptable for you?	As most farmers have difficulties to figure the rough proportion of residues left on the soil, answers do not completely reflect what they are actually ready to do.
8.10 What are the two more important factors that influence your own decision to use a specific farming practice?	The spectrum of possible answers (11) was too wide, with different levels of answers (those referring to where the know-how comes from; those referring to the ultimate goal behind choices; those referring to other opportunities enabled by choices). The answers lacked nuances and tended to be simplistic.
9.1 Do you feel that you are limited in your farm investments by your land rights?	There may have been a confusion between land rights (full ownership or individualized collective land) and lack of land.
10.7 Could you rank what you perceive as the two most severe risks for your crops and livestock in the future?	Interviewees probably lacked time to reflect on risks to their farming system. They were probably influenced by the fact that we were discussing about “drought” in the last 5 minutes. Therefore the “drought” risk may have overshadowed other risks
10.8 Could you rank what you perceive as the most likely risks for your crops and livestock in the future?	This question was progressively abandoned since it appeared that the difference between the severity and the likelihood of a risk was too subtle to be properly explained with the farmers’ words
10.11 In case the precipitation is predicted to be low or delayed at the beginning of the agricultural cycle, how flexible to adjust your plans and practices do you think you are?	Darija words were probably lacking to describe what “flexibility” means

Moreover, in this report, means are presented alongside medians, which may better reflect the circumstances of an average farmer, because of the sample size.

2.3.4 Data processing and analysis

New variables

A number of new variables resulting from calculations based on other variables were created:

- Ratio fallow-leguminous / cereals (%)

This variable aims to weigh the importance of fallow and leguminous areas in the total cultivated area (in ha). This new variable was mostly used as an explanatory variable for specific practices or perceptions.

$$x = \frac{Forage\ pea\ [ha] + forage\ mixture\ [ha] + medicago\ [ha] + pulses\ [ha] + weedy\ fallow\ [ha]}{total\ cultivated\ area\ [ha]} \times 100$$

- Potential gross incomes from cereal grain (MAD.year^{-1})

$$x = incomes\ from\ bread\ wheat + incomes\ from\ durum\ wheat + incomes\ from\ barley$$

with

$Incomes\ from\ bread\ wheat\ [MAD] = (bread\ wheat\ area\ [ha] - bread\ wheat\ area\ directly\ grazed[ha]) \times yield\ [q.ha^{-1}] \times price\ [MAD.q^{-1}]$

$Incomes\ from\ durum\ wheat\ [MAD] = (durum\ wheat\ area\ [ha] - durum\ wheat\ area\ directly\ grazed[ha]) \times yield\ [q.ha^{-1}] \times price\ [MAD.q^{-1}]$

$Incomes\ from\ barley\ [MAD] = price\ [MAD.q^{-1}] \times (((barley\ area\ [ha] - barley\ area\ directly\ grazed[ha]) \times yield\ [q.ha^{-1}]) - barley\ grain\ feed\ need[q])$

This variable was calculated for normal, good and dry years.

- Stubble production (kg.ha^{-1})

$$x = \frac{cereals\ biomass\ [kg] - straw\ production\ [kg]}{cereals\ area\ [ha]}$$

with

$Cereals\ biomass\ [kg] = total\ grain\ production\ [kg] * 60\%\ [based\ on\ harvest\ index]$

$Total\ grain\ production\ [kg] = bread\ wheat\ yield\ [kg.ha^{-1}] \times bread\ wheat\ area\ [ha] + durum\ wheat\ yield\ [kg.ha^{-1}] \times durum\ wheat\ area\ [ha] + barley\ wheat\ yield\ [kg.ha^{-1}] \times barley\ area\ [ha]$

$Straw\ production\ [kg] = 15 \times (bread\ wheat\ straw\ yield\ [bale.ha^{-1}] + durum\ wheat\ straw\ yield\ [bale.ha^{-1}] + barley\ straw\ yield\ [bale.ha^{-1}])$

For the estimation of biomass production, we used a harvest index of 40% (Platform Characterization, CANA, 2015). As regards straw, a bale is equivalent to 15-17 kg; therefore we averaged at 15 kg. This variable was calculated for normal, good and dry years.

- Straw bales packing costs (kg.ha^{-1})

$$x = \frac{straw\ production\ [bale] \times 15\ [kg] \times straw\ bales\ packing\ unit\ costs\ [MAD.bale^{-1}]}{cereals\ area\ [ha]}$$

with

$Straw\ bales\ packing\ unit\ costs = straw\ baling\ cost\ [MAD.bale^{-1}] + bales\ transport\ cost\ [MAD.bale^{-1}] + stack\ construction\ cost\ [MAD.bale^{-1}]\ )$

This variable was calculated for normal, good and dry years.

- Gross direct incomes from crop residues (MAD)

$$x = incomes\ from\ straw\ sales\ [MAD] + incomes\ from\ plot\ rent\ for\ stubble\ grazing\ [MAD]$$

with

$Incomes\ from\ straw\ sales\ [MAD] = straw\ production\ [bale] \times part\ of\ straw\ traded\ [\%] \times straw\ price\ [MAD]$

$$Incomes\ from\ plot\ rent\ for\ stubble\ grazing\ [MAD] \\ = cereals\ area\ [ha] \times part\ of\ stubble\ grazed\ by\ other\ flocks\ [\%] \times stubble\ grazing\ rent\ price^{2}\ [MAD.ha^{1}]$$

This variable does not encompass indirect incomes involved by the effect of straw and stubble on livestock and crop performances. This variable was calculated for normal, good and dry years.

- Contribution of residues to cereals direct incomes (%)

$$x = \frac{gross\ direct\ incomes\ from\ crop\ residues\ [MAD]}{potential\ incomes\ from\ cereal\ grain\ [MAD] + gross\ direct\ incomes\ from\ residues\ [MAD]} \times 100$$

This variable was calculated for normal, good and dry years.

- Net direct incomes from cereal residues (MAD)

$$x = gross\ income\ from\ crop\ residues\ [MAD] - (straw\ bales\ packing\ cost\ [MAD] + stubble\ plowing\ cost\ [MAD])$$

with

$$Stubble\ plowing\ cost\ [MAD] = machinery\ cost\ [MAD.ha^{1}] \times cereals\ area\ [ha]$$

This variable was calculated for normal, good and dry years.

- Flock size (Tropical Livestock Units, TLU)[3]

$$x = number\ of\ ewes\ \times 0.11 + number\ of\ rams\ \times 0.15 + number\ of\ lambs\ \times 0.05 + number\ of\ cows\ \times 0.7 + \\ number\ of\ calves\ \times 0.4 + number\ of\ horses\ \&\ donkeys\ \times 0.8$$

- Stocking rate ($TLU.ha^{-1}$)

$$x = \frac{flock\ size\ [TLU]}{cultivated\ area\ [ha]}$$

- Feed expenditure ($MAD.year.TLU^{-1}$)

$$x = \frac{Expenditure\ (barley\ + maize + bran + straw + forage\ hay + concentrate)[MAD]}{flock\ size\ [TLU]}$$

This variable was calculated for normal and dry years.

Simple costs and benefits analysis for a 50% retention of straw along with 100% stubble retention

For this calculation a number of assumptions were done:

- The parameters of crop residues retention were aligned with the parameters of the long-term experiment conducted by R. Mrabet in Chaouia (2011). In this experiment, all stubble (~10-15 cm high) was left as well as 50% of loose residues i.e. straw.
- Missing stubble and straw should be replaced by a forage mixture (pea-barley) produced on the farm. In the sake of clarity, other feed alternatives were ruled out.
- The forage mixture area was calculated on the basis of the forage production necessary to provide equivalent feed amount to the residues removed. The amount of feed from residues covered all the stubble produced on the farm, the equivalent of stubble grazed on other plots with payment of fees, and half of the straw. The latter was determined only for farmers who reported more than 50% of straw used for stall feeding. The part of straw traded or left on the soil was then withdrawn from 50. We assumed indeed that farmers invited to reduce straw removal would in priority reduce the part of straw for trade.
- To calculate the equivalence between residues and forage, we considered the Crude Protein content (CP), irrespective of the Crude Fiber (which is lower in forage mixtures). In order to simplify the calculations, we estimated that one unit of forage mixture would provide twice more CP. Based on CANA experiments, we used an average yield of 5 $t.ha^{-1}$. The forage mixture area was derived from these calculations.

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[2] Only for those who reported incomes from stubble grazing rent.

[3] Based on King et al., 1984

- The production of forage mixture involves a reduction in the cereals cultivated area (barley in priority), which results in a loss of incomes from straw and grain sales
- The conversion of cereals plots into forage mixture plots entails differentiated production costs. In this analysis, it is assumed that farmers practicing no tillage would adopt stubble retention. Therefore, we only considered the relative change in the production costs between two no-till systems, one with cereals and one with a pea-barley mix. Based on INRA's economic evaluations (Boughlala et al., 2015b), forage mixture cropping involves an increase in seeds, labour and baling costs per hectare, and a decrease in fertilizers and chemicals costs, in comparison with cereals, while seeder and transport costs are similar.
- The retention of 50% of straw lowers the capacity of farmers to trade surplus straw.
- The absence of revenues from plot rent for stubble grazing was taken into account in the system with residues retention
- In the retention system, an increase of fertilizers and herbicides costs in cereals plots was applied, in order to compensate for the risk of temporary N immobilization (Ichir et al., 2002) and weed proliferation (Midwood et al., 2011) in early years of crop residues retention adoption. An increase by 10% was arbitrarily chosen (from 1,000 to 1,100 $MAD.ha^{-1}$).
- The indirect virtuous effects of forage mixtures on livestock gross margin via enhanced animal nutrition were not included in this analysis. Nor were potential additional costs in terms of watchmen or fencing, to ensure that plots are not grazed.
- Benefits of stubble retention translate into a cereals' yield increase. Quantifying this increase is a thorny question, given the low number of experiments with crop residues retention in Morocco and the variability of results. Referring to experiments conducted by R. Mrabet (2011), we decided to apply a + 15% yield increase for farmers with conventional tillage (who would adopt both no-till and stubble retention) and a +5% yield increase for farmers already in no-till. Temporal variability of yield increase (stronger after several years than in the first years) was not tackled here.
- The division by two of the straw bales packing costs (50% of straw is removed) is another benefit of residues retention, as well as the suppression of stubble ploughing in summer.
- We assumed that, when a farmer indicated a price of grain, the totality of grain harvest is sold (which is probably not exactly the reality as farmers may keep a small part for household consumption)
- The analysis was done with the figures of a normal year

$$\begin{aligned}&\textit{Costs increase } [MAD]\\&= \textit{loss of earnings from straw sales } [MAD] + \textit{loss of incomes from cereals converted to forage } [MAD]\\&+ \textit{difference of forage seeds cost } [MAD] + \textit{difference of forage labour cost } [MAD]\\&+ \textit{difference of forage baling cost } [MAD] + \textit{loss of earnings from plot rent for stubble grazing } [MAD]\\&+ \textit{fertilizers \& herbicides cost increase } [MAD]\end{aligned}$$

With

$$\begin{aligned}&\textit{Loss of earnings from straw sales } [MAD]\\&= \textit{straw production } [bale] \times \textit{part of straw retention taken from sales } [\%] \times 17\ [MAD]\end{aligned}$$

$$\begin{aligned}&\textit{Part of straw retention taken from sales } [\%]\\&= 50 - \textit{part of straw retention taken from feed } [\%] - \textit{part of straw left on the soil } [\%]\end{aligned}$$

$$\begin{aligned}&\textit{Part of straw retention taken from feed } [\%]\\&= 50 - \textit{part of straw traded } [\%]\ \textit{part of straw left on the soil } [\%]\end{aligned}$$

$$\begin{aligned}&\textit{Loss of incomes from cereals converted to forage } [MAD]\\&= \textit{forage mixture area for equivalent } 100\%\ \textit{stubble and } 50\%\ \textit{straw crude protein } [ha] \times (\textit{cereals yield } [q.ha^{-1}]\\&\times \textit{cereals price } [MAD.q^{-1}] + \textit{straw yield } [bale.ha^{-1}] \times \textit{part of straw traded } [\%] \times \textit{straw price } [MAD])\end{aligned}$$

$$\begin{aligned}&\textit{Forage mixture area for equivalent } 100\%\ \textit{stubble and } 50\%\ \textit{straw crude protein } [ha]\\&= \textit{residues withdrawn from feed } [kg] \div 2\ [\textit{Crude Protein ratio}] \div 5000\ [kg]\end{aligned}$$

$$\begin{aligned}&\textit{Difference of seeds cost } [MAD]\\&= \textit{forage mixture area for equivalent } 100\%\ \textit{stubble and } 50\%\ \textit{straw crude protein } [ha] \times 40\end{aligned}$$

$$\begin{aligned}&\textit{Difference of labour cost } [MAD]\\&= \textit{forage mixture area for equivalent } 100\%\ \textit{stubble and } 50\%\ \textit{straw crude protein } [ha] \times 250\end{aligned}$$

$$Difference\ of\ baling\ cost\ [MAD] = forage\ mixture\ area\ for\ equivalent\ 100\%\ stubble\ and\ 50\%\ straw\ crude\ protein\ [ha] \times 340$$

$$Fertilizers\ \&\ herbicides\ cost\ increase\ [MAD] = 100 \times (cereals\ area\ [ha] - forage\ mixture\ area\ for\ equivalent\ 50\%\ stubble\ crude\ fibre\ [ha])$$

$$Benefits\ increase\ [MAD] = incomes\ increase\ from\ cereals\ grain\ [MAD] + incomes\ increase\ from\ cereals\ straw\ [MAD] + difference\ of\ fertilizers\ cost\ [MAD] + difference\ of\ chemicals\ cost\ [MAD] + no\ stubble\ grazing\ rights\ [\mathrm{MAD}] + no\ stubble\ plowing\ [MAD] + straw\ baling\ costs\ reduction\ [MAD]$$

with

$$Incomes\ increase\ from\ cereals\ grain\ [MAD] = grain\ production\ [q] \times 1.05^{4}\ or\ 1.15^{5} \times grain\ price\ [MAD]$$

$$Incomes\ increase\ from\ cereals\ straw\ [MAD] = straw\ production\ [q] \times 1.05\ or\ 1.15 \times part\ of\ straw\ traded\ [\%] \times straw\ price\ [MAD]$$

$$Difference\ of\ fertilizers\ cost\ [MAD] = forage\ mixture\ area\ for\ equivalent\ 50\%\ stubble\ crude\ fibre\ [ha] \times 80$$

$$Difference\ of\ chemicals\ cost\ [MAD] = forage\ mixture\ area\ for\ equivalent\ 50\%\ stubble\ crude\ fibre\ [ha] \times 520$$

$$Straw\ baling\ costs\ reduction\ [MAD] = straw\ bales\ packing\ cost\ [MAD] \div 2$$

Correlations

Bivariate correlations between key variables were identified using the Spearman method. A number of explanatory variables for farmers' behaviours (e.g. residues management) and perceptions (e.g. constraints to conservation agriculture, risks) or farm performances (e.g. yields, incomes) were found amongst farm characteristics (e.g. cultivated area, flock size, stocking rate, membership in organizations, land rights, tillage). Significant correlations (*: at 0.01 level, and **: 0.05 level) are highlighted in this report.

Factor Analysis

A component matrix with factors loading was extracted from a number of key variables, chosen upon judgemental selection (Table 4).

Table 4 - Variables used for factor analysis

Community	Most important production system
Age	Sectors contributing to yearly incomes
Involvement in CANA project	Flock size (TLU)
Farmers' organization membership	Stocking rate ($TLU.ha^{-1}$)
Land rights	Number of fattened sheep
Cultivated area (ha)	Height of straw cut (normal year)
Ratio fallow-leguminous / cereals	Stubble left on soil (normal year)
Rotation	Residues contribution to cereal incomes (normal year)
Tillage	Residues contribution to cereal incomes (dry year)
Barley grain yield (normal year)	Crop residues net incomes (normal year)
Barley straw yield (normal year)	Feed expenditure in normal year
Potential incomes from cereal grain (normal year)	Unconsented grazing
	Stubble ploughing

Factor analysis enabled the identification of 7 factors with significant explained variance, based on inter-correlations between multiple variables.

[4] No-till farmers
[5] Conventional farmers

3. Results

3.1 Characteristics and history of crop residues management

In this part, we answer the first sub research question: *"What are the current characteristics and history of crop residues management?"*. To this end, we first outline a history of land use and crop residues management before describing the current patterns of crop residues production and use.

3.1.1 History of land use and crop residues management

The management of crop residues is narrowly associated to historic, climatic, land use and technical evolutions (Figure 5, Figure 6). Smaala and Beni Khirane communities, albeit geographically close to each other, followed different pathways, which have resulted in significant differences in terms of land and residues management. Nonetheless, the contemporary agricultural history of these two communities has been shaped by two milestones: the land management changes undertaken under the colonial rule and their legacy right after the independence; and the catastrophic droughts of the early 1980's.

Land use

In the first half of the 20th century, Oued Zem region was located in transhumance corridors between Southern dry areas and Northern pasturelands. More and more herders progressively settled and started to practice small-scale agriculture in rain-fed lands (Hicham D., 09.2015). Most of the farmers today are the heirs of these herders: they have inherited their land rights, the cultural value of livestock and a pastoralist perception of natural resources. Beni Khirane community is more firmly anchored in these pastoralist roots than Smaala community (M. El Koudrim, personal communication).

Until the 1930's, Smaala rangelands were used as collective pastures and for game hunting. The French settlers instigated croplands expansion after clearing these areas occupied by sparse vegetation (e.g. jujubes, chamaerops), until the 1950's. Land was then privatized. After independence, former settlers' estates were managed by a public institution, SOGETA (Société de Gestion des Territoires Agricoles), from 1965 to 1971. This transition through a public management laid the foundations of a relatively equitable access to land. In 1971, pieces of land were distributed to all local farmers. A cooperative was then put in place. The cooperative does still exist, although it is not very active and gathers a minority of farmers (30%, based on the household survey). During the FGD, farmers admitted that they are less connected to one another than in the past.

In contrast, the French protectorate didn't convert Beni Khirane area into croplands. The expansion of rain-fed farms was triggered in the years following independence (1956) by the national operation "mechanized clearing". Aiming to use mechanized tillage to offer arable lands to a growing rural population (composed of herders willing to settle), this operation allowed the gradual conquest of rain-fed areas by agriculture. Clearing out and cultivating new lands was also a manner for families to claim rights on these lands.

These different pathways influenced access to land as of today. With a significant number of large-holders (18% own more than 50 ha) alongside a growing number of small-holders (36% own less than 10 ha), Beni Khirane agricultural population is more heterogeneous in terms of cultivated area than in Smaala, where farmers owners cultivating less than 20 ha are predominant (Chart 1).

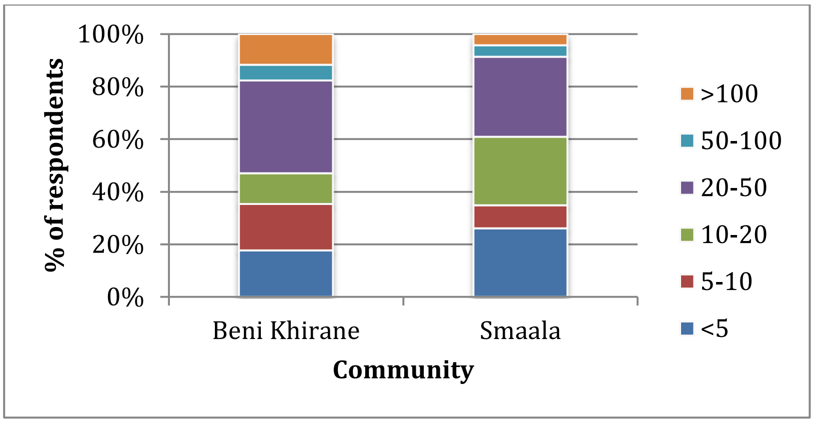

Chart 1 - Cultivated area classes in the two communities (classes in ha; % of respondents)

Droughts

Up to the 1960's, rainfalls were steady and sufficient (FGD Beni Khirane). Precipitation records confirm an overall decline from the 1970's, which translated into more inter-annual variability and the occurrence of droughts (ICARDA-INRA, Characterization of the Moroccan platform, 2015). A succession of catastrophic droughts occurred in the first half of the 1980's (1981, 1983, 1985). Farmers have an agronomic definition of what a drought is: as it happens, catastrophic droughts are remembered for the absence of crop production. Since these extreme events, three catastrophic droughts were reported (1994, 1995, 2001), but none was reported in both the two focus-group discussions. The absence of catastrophic drought in the last 15 years reflects more an improved adaptive capacity than a real change in precipitation patterns. Farmers now define three types of years: dry years are characterized by low production; normal years by an average production; and good years by fairly high yields. The recurrence of droughts has become regular. The last drought occurred in 2013-2014 (210 mm).

Crops management

The droughts of the 1980's and their dramatic consequences (food insecurity, de-stocking, migrations) spurred farmers and policymakers into realizing changes in agro-climatic circumstances, which in turn entailed the acceleration of mutations already started in the 1970's.

Photo 2 - Mechanized tillage in Chaouia (old postcard, French time)

Traditional and mechanized agriculture coexisted up to the 1980's. Superficial animal tillage and seeds broadcasting were still common practices. The generalization of tractors, introduced in the 1940's, was accelerated in the mid-1970's thanks to national subsidies (in Beni Khirane) or via SOGETA and the cooperative in Smaala. In the 1990's, mechanized agriculture had totally replaced the traditional system. Mechanization became an adaptation strategy to overcome the disappearance of draught animals (sold after the droughts) and the manpower reduction triggered by increasing rural-urban migrations. Until the beginning of the no-till project led by INRA, the necessity of deep ploughing was firmly rooted in the farmers' beliefs.

Before the droughts, the precipitation abundance allowed a rotation with fallow every two years. In Smaala, cereals alternated with weedy fallow or forage pea. After the droughts in the 1980’s, two-year rotations became rarer. Barley, more resistant to water shortage, became popular again, while bread wheat had been introduced through a national program in the 1970’s.

In Smaala, farmers reported a general erosion of cereal yields since the 1980’s, including in normal years. Nevertheless, Beni Khirane focus group admitted that the popularization of mechanization and chemical fertilizers enabled keeping up and, for some farmers, improving the yields. Nowadays, more and more farmers recognize the positive effects of weedy fallow.

Livestock feeding

Until the 1960’s, flocks grazed in collective pastures and were fed with straw in winter. Bran (hard outer layer of cereal grain) and fodder crops were introduced in Smaala in the early 1970’s. Supplementation from September, after three months of stubble grazing, became common from the 1990’s in Beni Khirane. Considerable numbers of animals were sold after the severe droughts of the early 1980’s, due to difficulties to feed them (up to 80% of livestock losses reported in Beni Khirane). Smaala farmers remember they had to go to Oujda, more than 600 km far, to find straw in 1985.

Improvement of livestock feed in dry years had substantiated effects on mortality rates (in our survey, 50% of the respondents said that there is no change in stillborn rates in dry years, while 35.3% reported a moderate increase and 14.7% a sharp increase).

Crop residues management

Cattle and small ruminants grazed stubble since the 1930’s. Stubble was free of access.

In the 1970’s, it was common to burn stubble, following an instruction from the ministry to eradicate an insect. This practice stopped in most farms but is still applied by few farmers.

Mechanized straw balers were brought to the farmers from 1981 on and replaced manual straw collection (Photo 2). This technical shift optimizing biomass use was motivated by the sudden soaring of the straw value, caused by droughts. Before, more straw was left on the soil and buried by animal trampling and ploughing. The use of straw baler changed the height of straw cut, which averaged around 30 cm before the 1980’s and which is less than 10 cm in dry years, nowadays.

Photo 3 - Straw collection in Chaouia (old postcard, probably after independence)

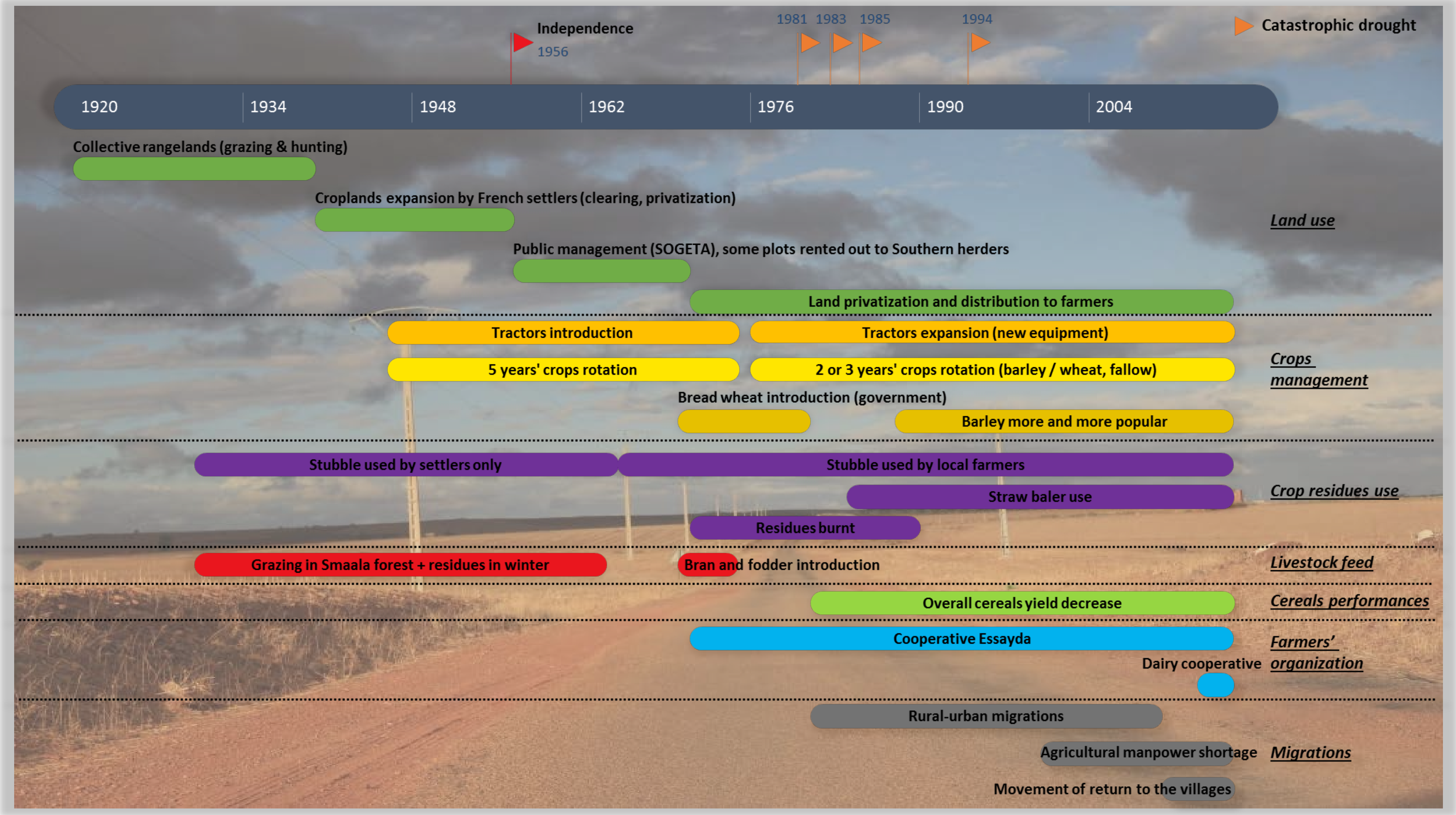

Figure 5 - Land use and crop residues management timeline (Smaala community)

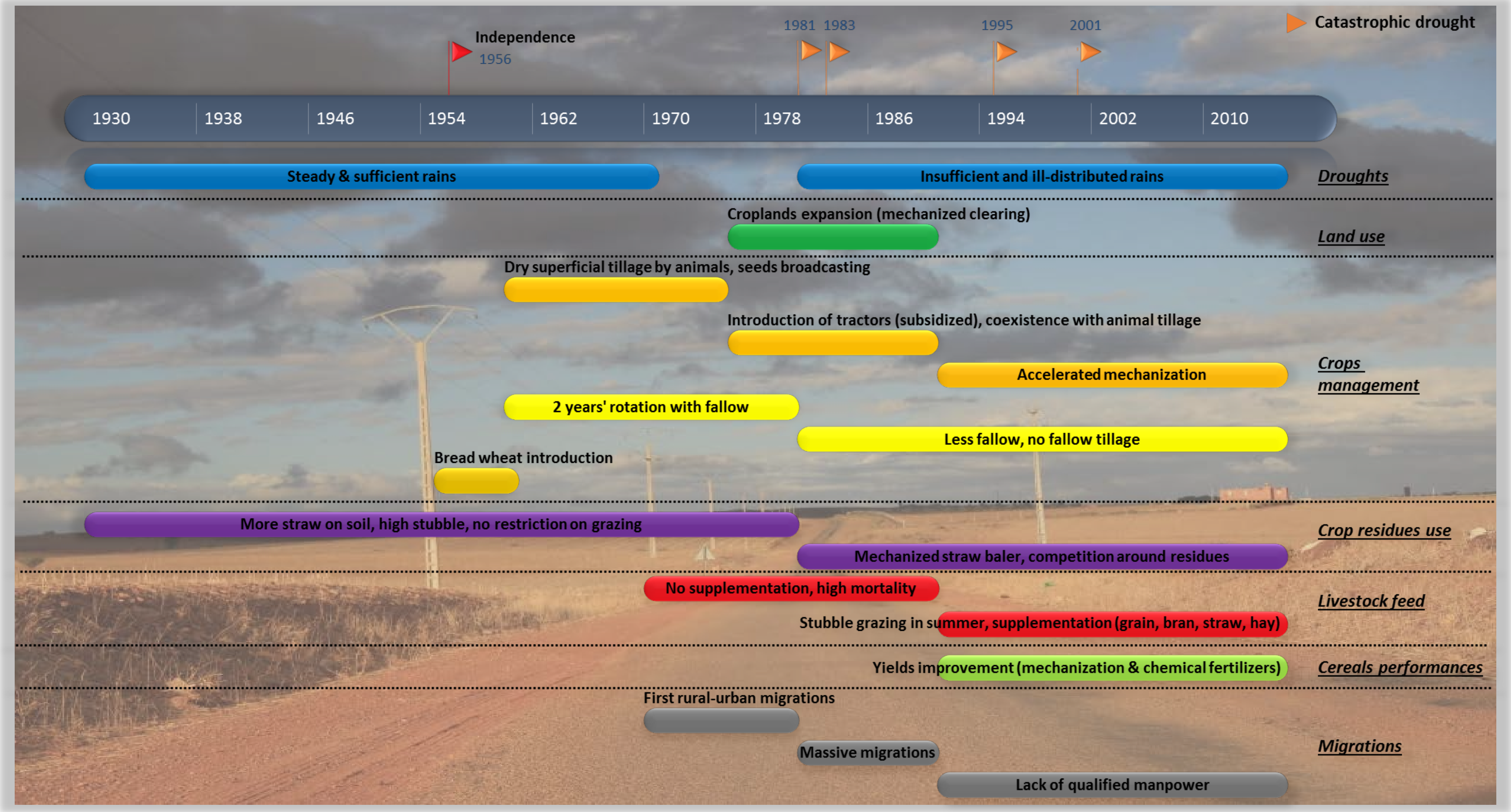

Figure 6 - Land use and crop residues management timeline (Beni Khirane community)

3.1.2 Crop residues production

Straw production

Straw production is characterized by high inter-annual variability (Chart 2). The very low straw production records in dry years (11 to 20 bales.ha^{-1} for the three cereals) give an important indication on the uncertainty of this resource.

Barley straw yields are significantly higher than wheat straw yields, including in dry years. These figures confirm the renewed interest of farmers in barley since the catastrophic droughts of the 1980's (FGD Beni Khirane, 2015). Barley is believed to be more resistant in dry years for both grain and straw. Barley straw is also preferred for its nutritive quality (FGD Beni Khirane, 2015). Durum wheat supplies more straw than bread wheat in dry years (also reported in FGD), and its quality is preferred as well.

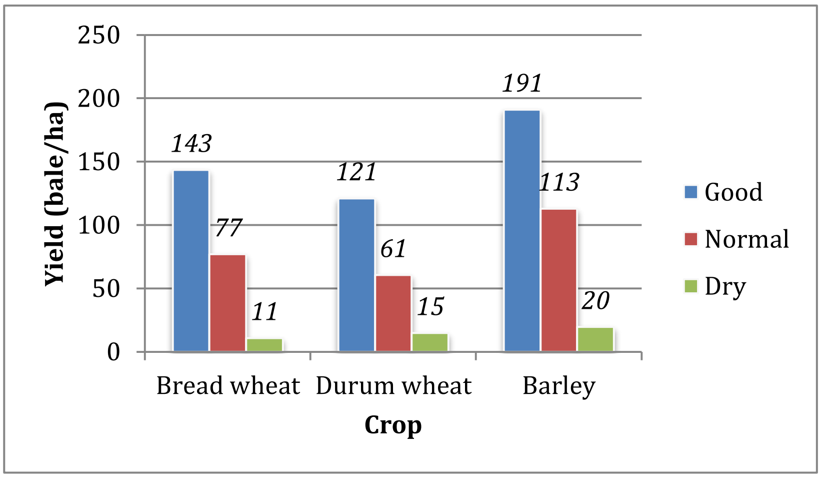

Chart 2 - Average straw yield in normal, good and dry years (bale.ha^{-1})

Stubble production

Median yield of cereals stubble decreases substantially in dry years, from 1.2 to 0.65 t.ha^{-1} (Chart 3). These figures can be compared with the crop residues researcher-managed experiment led by INRA in the CANA project, where stubble yield ranged from 1.5 to 3.5 t.ha^{-1} (depending on the plots) in a good year, and 1.2 t.ha^{-1} in a dry year (El Koudrim, 2015, unpublished). Discrepancies may be explained by the high spatial variability inherent in stubble production, implied by the height of straw cut for instance. In the household survey, standards deviation is 507 in a dry year.

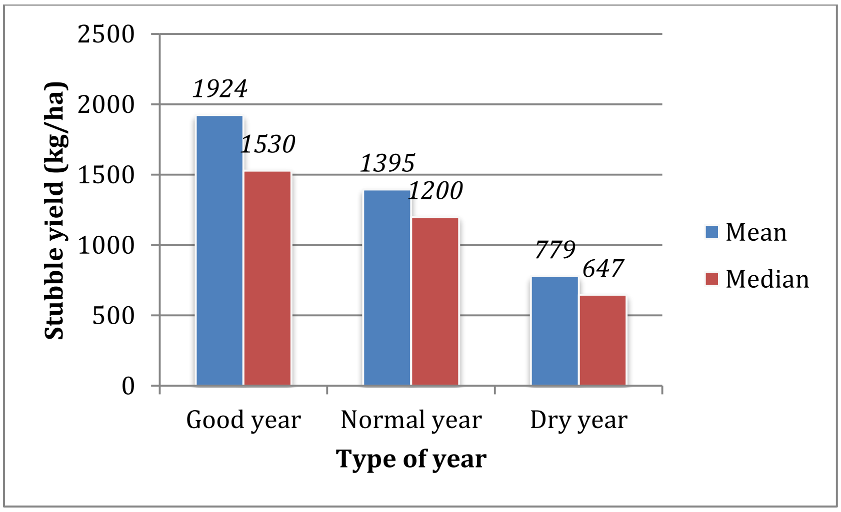

Chart 3 –Mean and median cereals stubble yield in normal, good and dry years (kg.ha^{-1})

Farmers do not appreciate the amount of stubble available in terms of quantity, but, for some of them, in terms of grazing potential (Table 5). Farmers estimate that they roughly have 90 days of grazing for a 20-ewes flock in a normal year, 120 in a good year and 25 in a dry year (medians). No farmer did indicate being able to graze more than one month in a dry year, but it doesn't mean that there is no stubble left.

Table 5 - Stubble production statistics, for two methods of estimation

Stubble production		Normal year	Good year	Dry year
Number of days of grazing for a 20-ewes flock	Mean	91.81	109.58	23.33
	Median	90.00	120.00	25.00
	Standard deviation	23.729	15.963	7.071
	Minimum	30	60	5
	Maximum	120	120	30
$Kg.ha^{-1}$ (on the basis of an harvest index of 40%)	Mean	1395.27	1924.08	779.13
	Median	1200.00	1530.00	647.50
	Standard deviation	707.09	1280.88	507.93
	Minimum	150.00	.00	129.00
	Maximum	3686.00	6176.00	2250.00

Species and varieties

Biomass productivity is determined by species and varieties, although these factors are outweighed by rainfalls and N fertilization (El Gharras et al., 2009).

A local variety of barley, known to be particularly drought-resistant, is widely sown in the area (FGD, 2015) and beyond: Oued Zem region is indeed the first region in Morocco for barley seeds production (O. El Gharras, personal communication).

Farmers from Smaala FGD reported that improved varieties of bread wheat produce less biomass than former local varieties, which have nearly disappeared though. This limit has historically been a factor for the low adoption of dwarf varieties in the Green Revolution (Magnan et al., 2012). It confirms the weak penetration of certified seeds through Morocco, due to high pricing and problems of availability in rural areas (Aït El Mekki, 2006).

The straw potential of varieties is taken into account by farmers. It is rarely the first criterion of seeds selection (FGD Smaala, 2015) but most farmers value the straw potential of varieties as much as their grain potential, which remains the main sought quality (charts in Annex V).

In addition, 25% of the interviewed farmers purposely increase the seeding rate (up to 200 kg/ha, broadcasting) to increase biomass production, even though many of them reported that this is not valid for barley due to natural tillering.

Residues removal techniques

Farmers adjust the height of straw cut operated by the reaper, depending on their respective straw and stubble needs. In good and normal years, the median stubble height is 20 cm while it decreases to 10 cm in dry years, so as to obtain more straw bales. 20.5% of the respondents leave 5-cm tall stubble after straw cut in a dry year. Some farmers indicated that the height of cut also depends on stones density thus on the soil type (Chabli M.). All in all, the choice of the cut height is also limited by the machinery capacity. Most farmers solicit local service providers, who apply standardized adjustments.

The second stage of the technical itinerary consists of packing straw left on the ground into bales, and building stacks. This stage can be sub-divided into three steps: baling, bales transport and stack construction. Few farmers mentioned the extra use of straw crusher before straw bales making.

A mechanized straw baler is used by all farmers for baling. Most farmers apply one baler passage. We interviewed two farmers (out of 40) who usually pass the baler two times. Adding a second passage is intended to maximize the volume of straw but it reduces residues availability on the ground. It is only adapted to high volumes of biomass. A second baler passage requires the use of a tedder (*râteau-faneur-andaineur* in French) to break up straw and turn over windrows. The cost varies between 200 and 500 MAD.ha^{-1}.

The baling cost is standardized by service providers but may vary as a function of the packaging type: string binding costs 2.5 or 3 MAD/bale while wire binding costs 3.5 or 4 MAD/bale. The median cost for our respondents was 3.5 MAD/bale. Straw bales transport costs 1 MAD/bale on average (from 0.5 to 2 MAD/bale). The cost of stack construction is 0.5 or 1 MAD/bale. These costs (3.5+1+1=5.5 MAD/bale) can be reduced if the farmer provides his own machinery and/or family manpower.

The baling cost per hectare is related to the straw yield. It averages around 550 MAD.ha^{-1} in a normal year and decreases to 119 MAD.ha^{-1} in a dry year. The total cost of this operation at farm level may in some cases represent a substantial expenditure for the farmer (Table 6). A median farmer spends MAD 3,875 (nearly USD 400) in a normal year. In a good year, this total raises to MAD 7,790 (nearly USD 800). This cost, result of higher yields, is ironically the other side of the coin. Large-scale farmers may spend up to MAD 363,000 for straw bales packing. We have here a first indication on the importance of straw in the household economy, as this importance justifies such a high level of expenses.

Table 6 - Total straw bales packing cost at farm level (MAD)

		Normal year	Good year	Dry year
N	Valid	40	40	40
	Missing	0	0	0
Mean		16352.688	28459.750	2299.638
Median		3875.000	7790.000	467.500
Standard deviation		40719.7592	65169.0027	5478.2140
Minimum		.0	385.0	.0
Maximum		233200.0	363000.0	26390.0

3.1.3 Crop residues use

Crop residues control

The question to farmers about the perception of their own control over their cereal residues gave contrasted answers (Chart 4). This question aimed to understand if farmers considered they could take the best advantage of residues; hence, if their strategies are thought to thoroughly maximize benefits from residues. The answers tend to show that control over this resource is far from optimal (only 30% consider their control “optimal”). This perception is related to different factors. The main one relates to the residues losses caused by unauthorized grazing. A significant negative correlation is observed between these two variables (-0.533). In this respect, 47% of Beni Khirane farmers asserted having a low control of their residues; while this negative perception decreases to 30% in Smaala, where farm boundaries are better respected by shepherds (this point will be explained further in the report). Other factors, quoted by respondents themselves, may fuel a feeling of weak control over the residues resource: these relate to the fact that the reaping work would entail straw losses, due to machinery flaws (e.g. height of cut not aligned with the farmer’s wishes) or even rip-offs by the service provider.

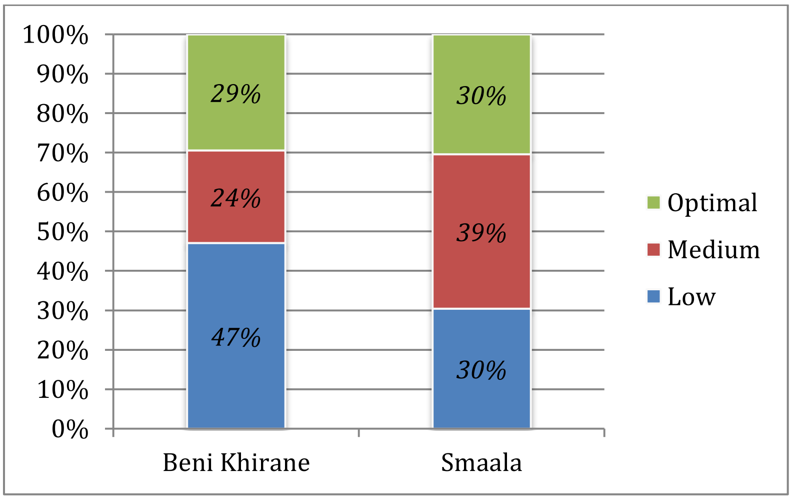

Chart 4 - Perceived control over crop residues use in the two communities (% of respondents)

Straw use

There are four functions of straw in Oued Zem region: stall feeding, trade, retention on the ground, and grazing (Chart 5). The importance of these functions substantially differs between a normal and a dry year. In a dry year, straw is proportionally less traded and directly serves animal feeding purposes, through stall feeding or direct grazing. In this region, straw is not used for fuel and construction.

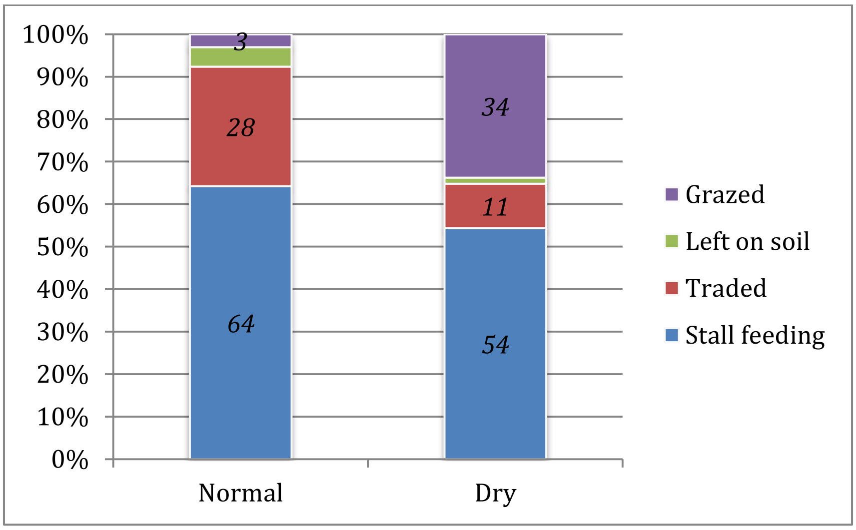

Chart 5 - Straw use in normal and dry years (average % of each function for all respondents)

Stall feeding is the primary function of straw for a majority of farmers. For 40% of the respondents, the totality of straw bales is dedicated to feeding animals in a normal year. In contrast, 15% of the respondents, who have no or little livestock, do not keep any straw for stall feeding.

45% of the interviewees do not trade any straw bales in a normal year. It increases to 87.5% in a dry year. It means that, although straw prices' inflation during droughts offers interesting opportunities to straw producers, only a few of them are actually in a position to trade straw because they are above all bound to feed their livestock. Moreover, only one farmer out of five trades more than half of his straw bales in a normal year. The market-oriented straw producer profile remains rare.

The farmers' propensity to trade straw in a normal year is correlated to a number of variables (Table 7). We observe a significant negative correlation with the stocking rate, which means that the less the density of animals per hectare is, the more farmers are susceptible to trade straw. This variable is also positively correlated to the potential incomes from cereals grain: in that sense, straw would not substitute to grain. Some correlations with the cropland area, the land rights, the type of tillage and the total feed expenditure in a normal year (negative) are also noted.

Table 7 - Correlations between proportion of straw traded and farm characteristics, in a normal year

Variable	Spearman correlation coefficient
Cultivated area (2015)	0.370*
Membership in farmers' organization	0.035
Land rights	0.347*
Ratio fallow-leguminous / cereals	-0.280
Tillage	0.318*
Most important production system	-0.296
Unconsented grazing	0.013
Number of TLU	-0.022
Stocking rate (TLU/ha)	-0.743**
Potential incomes from cereals grain	0.571**
Total feed expenditure in a normal year	-0.420*

The pattern "stall feeding vs trade" is disturbed by another common practice in dry years, which consists of not reaping the few quantity of grain & straw produced. Hence, cattle and small ruminants directly graze these plots. 62.5% of the farmers engage in this cost-saving strategy in dry years, and even 5% in normal years. For most of them, this practice is applied on a part of their parcels (Chart 6): in general, the most fertile parcels are reaped while remote, sloping and stony parcels are directly grazed. Nevertheless, 22.5% of the respondents reported the full grazing of their property in dry years.

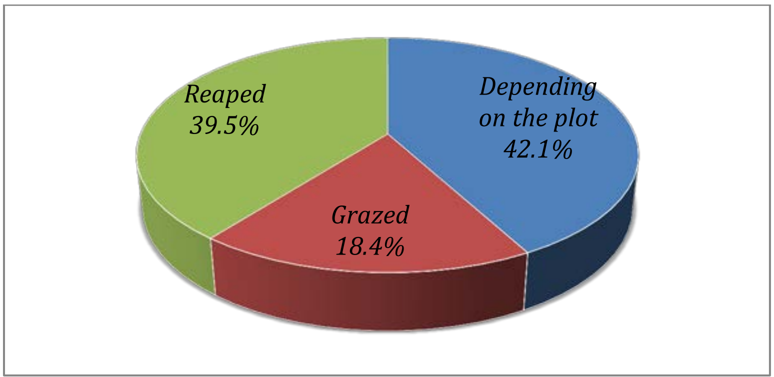

Chart 6 - Barley plot management in a dry year (% of respondents, n=38)

In addition, a minority of farmers (20%) mentioned that there was a bit of straw remaining on the ground after bales packing. It was mentioned in the focus group discussions that there is no point in leaving straw on the ground since it would be removed by wind.

Lastly, the bedding function (in stables and for poultry) is marginal and not accounted for by farmers. However, a part of the straw sales is dedicated to large-scale poultry producers in the whole country (O. El Gharras, personal communication).

Straw trade

The value of straw varies considerably from a year to another (Chart 7). Between a good and a dry year, it is multiplied by nearly 2 for wheat and 2.5 for barley. Barley straw is more expensive in all circumstances, but its added value in comparison with wheat straw is particularly striking in dry years.

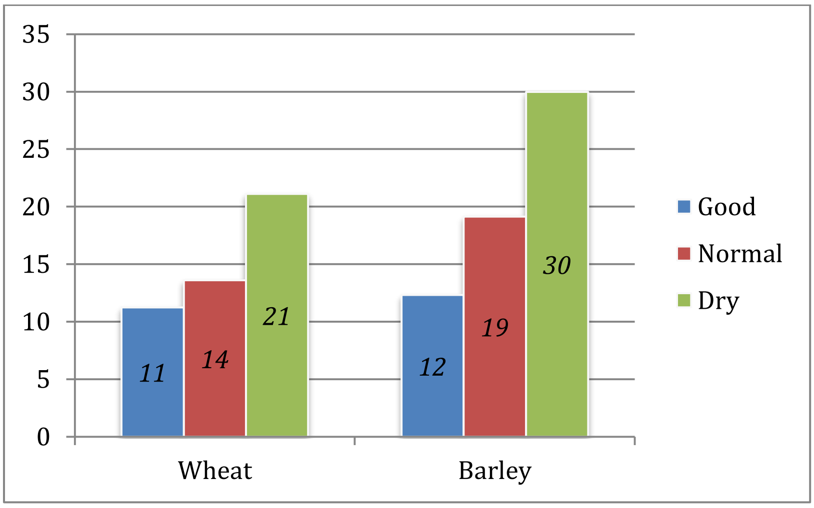

Chart 7 – Average wheat and barley straw price in normal, good and dry years (MAD.bale^{-1})

Nevertheless, the selling price of straw differs significantly between farmers. For instance, the price of a barley straw bale indicated by the respondents ranges from MAD 12 to 25 in a normal year. An analysis of correlations between barley straw price and farm characteristics shows a significant correlation with the membership in farmers' organization, and the involvement of the farmers' in the INRA/ICARDA project of conservation agriculture (Table 8). Both variables reflect the farmers' connectedness (farmers active in producers' organizations have supposedly better access to market information, and may take advantage of the organization to obtain better negotiations). In the FGD carried out in Smaala, participants stressed the competition over straw price between farmers as a sign of weak social cohesion.

Table 8 - Correlations between barley straw price in a normal year and farm characteristics

Variable	Spearman correlation coefficient
Cultivated area (2015)	0.138
Involvement in CANA project	0.520*
Membership in farmers' organization	0.797**
Height of straw cut in a normal year	0.060
Flock size (TLU)	0.355

Straw price variations depend on straw quality, bale weight (from 15 to 20 kg), binding type, access to markets and timing of trade. This latter is an important determinant. Most farmers do not sell straw at the same time, right after straw bales packing. They firstly estimate the amount necessary to livestock feeding and sell the remaining, trying to find the best balance between their cash needs and the profit they can generate. In this respect, they ideally aim to sell straw bales when market circumstances are more favorable, in normal or dry years, when straw needs are high (before winter). However, there is also a bet on the circumstances of the next year: if the year after turns to be a drought, farmers expect to rely on the bales previously stockpiled for their feed needs. In consequence, although the possibility to store straw offers some flexibility, decisions to sell or stockpile are thorny, dependent on vulnerability to drought risk, and lead to trade straw sparingly. As a result, farmers with a low stocking rate (mostly large-holders) have much more capacity to sell straw (Table 7).

When yields benefited from very generous rainfalls, straw price is considered very low by farmers. They usually have a minimum price, under which selling straw would be worthless (Table 9). This minimum averages around MAD 11 per bale (wheat and barley), which makes the farmer generate a net income of MAD 5 to 6 per bale. However, some smallholders admitted they could sell straw for MAD 7 per bale (MAD 1 to 2 of margin), if cash need is critical.

Table 9 - Average price of straw considered minimum by farmers to sell straw, compared to actual price in normal and good years (MAD.bale^{-1})

Sale price	Perceived minimum	Actual normal year	Actual good year
Wheat	10.8	13.6	11.3
Barley	11.6	19.1	12.3

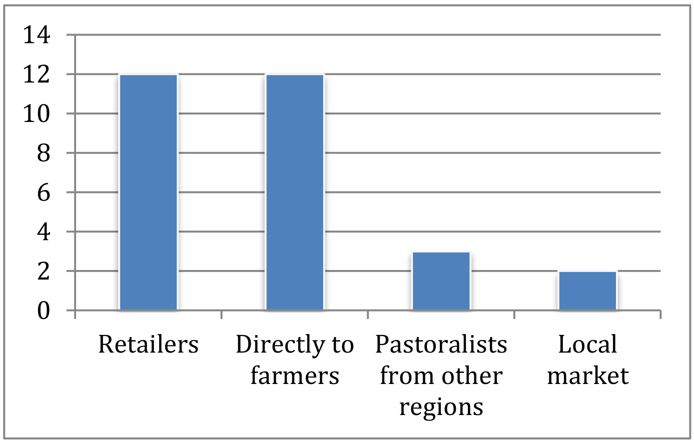

Chart 8 - Destination of straw sales (number of farmers, n=21)

Farmers from Oued Zem region sell straw mainly to retailers or directly to local farmers (Chart 8). It is common that herders from arid areas of Southern Morocco come to Chaouia-Ouardigha to buy straw. The province is a prominent supplier of straw for the whole country. Apparitions of trucks overflown with straw are usual. In normal years, 20 to 25 trucks of straw leave Ouled Boughadi village every day during several weeks (FGD Beni Khirane). The dynamism of straw trade in small rural markets even during the research (3 months after harvest) illustrates the importance of straw in local economies (Photo 4).

Photo 4 - A market in Smaala area (Gauny, 2015)

Straw storage

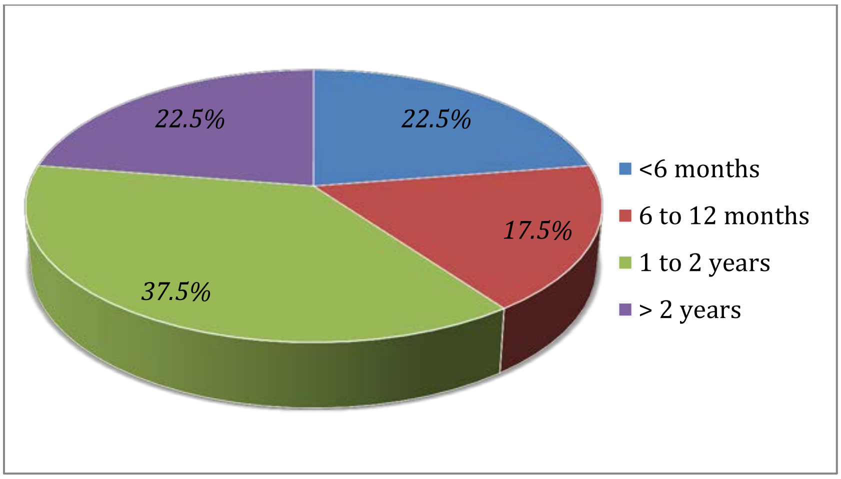

Chart 9 - Straw storage duration (% of respondents)

These strategies around straw trade go alongside different durations of straw storage (Chart 9). While 22.5% of the farmers do not store straw for more than a few months after harvest, a larger part of them stockpile straw during one to two years. Few farmers said that they could keep straw up to three years.

Straw bales are grouped in stacks near the farmer's house. Stacks are covered with a tarpaulin during the rainy season (Photo 5). Bad covering may alter the quality of some bales.

Photo 5 – Straw stack (Gauny, 2015)

Stubble use

Cereal stubble is largely used for grazing (land owner's flock or other flock): 79% in normal years, 90% in dry years, on average (Chart 10).

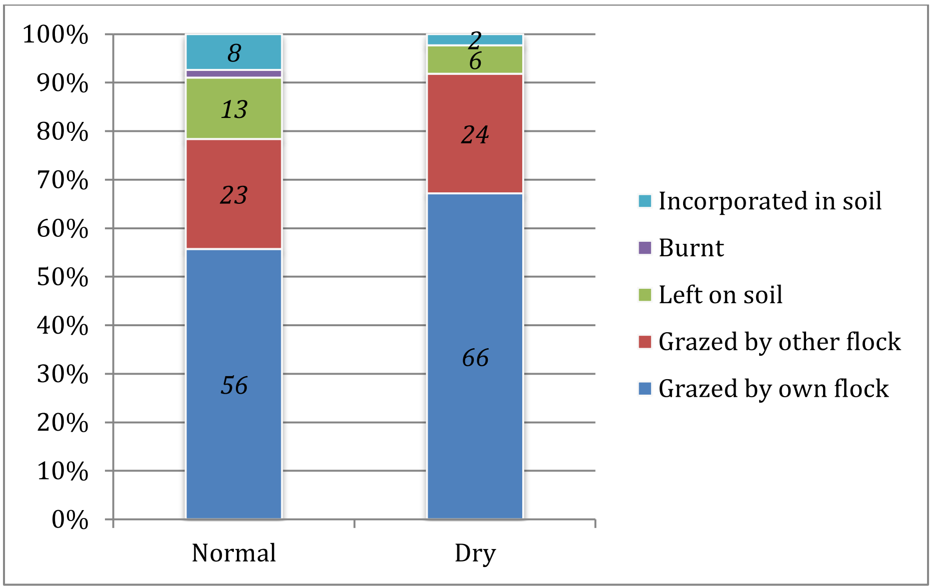

Chart 10 - Stubble use in normal and dry years (average % of each function for all respondents)

The proportion of stubble grazed by the land owner's livestock is very high in dry years. This percentage is significantly correlated to the stocking rate (Table 10). A negative correlation with the proportion of straw traded is identified as well: it means that those who are involved in some straw business are less dependent on stubble for grazing. We can also note that the age of the farmer is not a significant explanatory variable to stubble management.

Table 10 - Correlations between % of stubble grazed by own flock and farm characteristics (dry year)

Variable	Spearman correlation coefficient
Age	0.226
Cultivated area (2015)	-0.181
Tillage	-0.159
Most important production system	0.292
Unconsented grazing	0.283
Flock size (TLU)	0.025
Stocking rate (TLU/ha)	0.408**
Total feed expenditure in a normal year	0.015
Proportion of straw traded in a normal year	-0.454**

Based on farmers' estimates, an average of 13% of stubble is left on soil in normal years and 6% in dry years. However, the reality is more contrasted: in normal years, 47.5% of respondents do not retain any stubble, whereas 25% retain at least 1/5th (Chart 11). Two farmers from Smaala, who have no livestock and aren't exposed to unauthorized grazing, keep all stubble until next sowing. After a drought, stubble is fully exploited for feeding livestock (87.5% of respondents estimate that there is no stubble left).

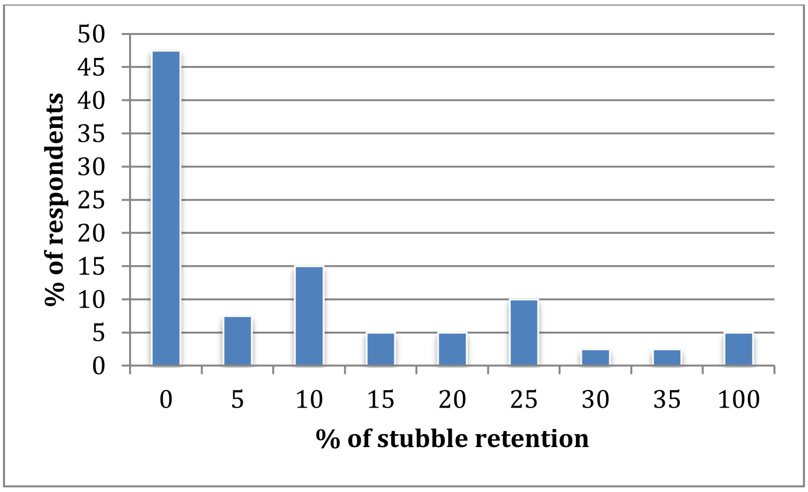

Chart 11 – Perceived percentage of stubble retention in a normal year (% of respondents)

The percentage of stubble retention in a normal year is significantly correlated to only one variable, "Tillage" (0,469). It is probably explained by the fact that those who have engaged with no till have heard some messages about the benefits of residues retention from INRA; and are in general crops-oriented large-scale farmers, with less pressure on residues for feed. Nonetheless, we could have expected a correlation with the stocking rate (TLU/ha) or the cropland area (ha).

Photo 6 - Which quantity of stubble is left? (photo taken mid-October, 3 to 4 months after harvest)

Figures given by farmers must be put into perspective, though. First, "no retention" is practically impossible: there will always be a small quantity of stubble not eaten by animals (Photo 5). Second, INRA-managed experiments show that, at sowing time, up to 500 kg.ha^{-1} of stubble are found in the farms, after 3 or 4 months of grazing. This amount is equivalent to 20 to 40% of stubble available after straw baling.

Two other practices concerning stubble are used in Oued Zem region: burning and stubble ploughing.

10% of farmers keep burning all residues after straw baling, for land amendment (see p. 21).

Summer stubble ploughing is a much more widespread practice (40% of respondents, in normal years). This operation is a superficial tillage (8-12 cm) usually carried out in summer, after few weeks of grazing, long before deep ploughing in autumn. It aims to break mounding, destroy weeds, improve soil fertility by returning residues (some farmers claimed this reason), but also to prevent grazing. In that sense, by incorporating remaining residues into soil, this preventive measure is intended to deprive neighbors of any benefits from free grazing. It is quite symbolic of some kind of distrust between natural resources users. In this respect, the fact that this practice is less popular in Smaala (43%) than in Beni Khirane (53% of farmers), where free grazing issues are more sensitive, is meaningful. Summer ploughing can be made with different types of machinery. The most common in this area is the chisel (74% of those who do stubble ploughing) but the use of the three-disc plough and the offset-pulverizer (also called "cover-crop") has been reported in this survey. Chisel is reportedly more adapted to compacted soil and cover-crop to looser soils. Summer ploughing with chisel costs 150 $MAD.ha^{-1}$. The farmers spend on average MAD 1,884 for the operation on the whole farm, or at least the parcels with the most compacted soils (effects are limited in shallow soils, El Gharras et al. 2015).

This practice is banned from the conservation agriculture portfolio proposed by the CANA project.

Further, minimal amounts of stubble are regularly used for construction (insulation of stables roofs, in particular).

Finally, stubble may be a direct source of incomes: few farmers (12.5%) regularly rent out some plots to other farmers after harvest. There is no rule in terms of price, which varies between 50 and 1,000 MAD/ha, whatever the duration.

Spatial variability

Some farmers adapt the management of cereal residues to the characteristics of the parcel. 25% of the respondents use to graze more residues in remote, in general less fertile, and less controlled plots. It means that land owners start grazing stubble in priority in these plots, after harvest. In contrast, there is probably more potential for retaining residues in closer plots. Similarly, residues in stony soils (*harch*) tend to be more grazed than those in softer soils.

Residues direct incomes

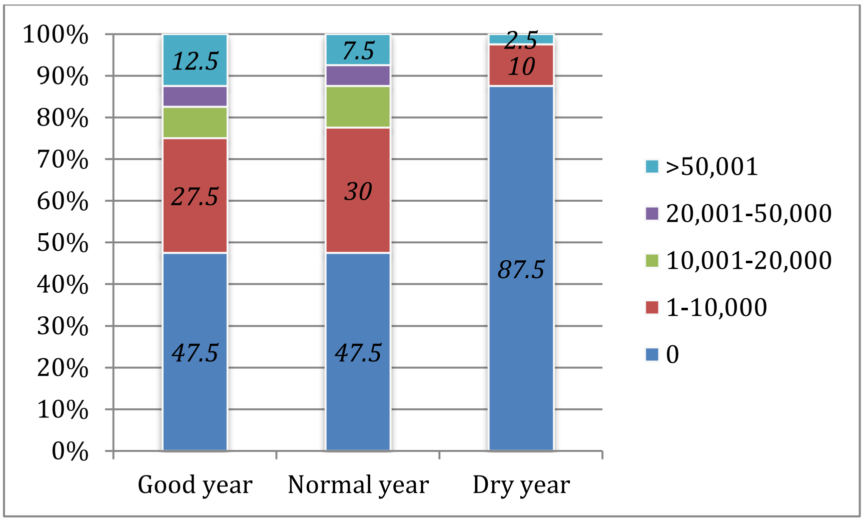

Chart 12 – Gross incomes from straw sales (per classes, in MAD) in different years (% of respondents)

Beside the indirect benefits of residues in terms of livestock feeding, straw and stubble generate some direct incomes to farmers. The reality of these incomes is highly heterogeneous.

In normal years, while 47.5% of the farmers have no incomes from straw sales and 30% earn less than MAD 10,000, 7.5% earn more than MAD 50,000 (more than USD 5,000). In dry years, only one farmer in the sample could earn more than MAD 10,000 (Chart 12).

The market price of straw is very low after good harvests. Nevertheless, looking at the total incomes from straw, one could wonder whether the higher volume of straw produced would compensate for this depreciation. Chart 13 shows that the situation is shared, between farmers who increase their gross incomes compared to a normal year (35%) and those whose incomes would be decreased due to the price reduction (17.5%).

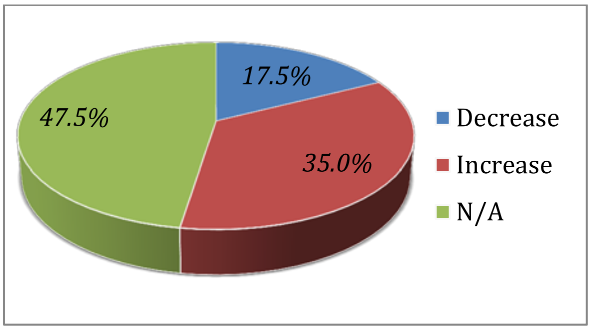

Chart 13 - Change in gross incomes from straw in a good year compared to a normal year (% of farmers)

Direct incomes from straw sales and grazing rent bring a minor contribution to cereal revenues (Table 11). Based on the median, this contribution is non-existent in dry years. Only 2 respondents out of 40 earn more incomes from residues than grain in normal years. This variable is significantly correlated to the cropland area (0,561). Therefore, except for few large-scale farmers, straw doesn't have a capacity to buffer a mediocre grain harvest in terms of cash flow.

Table 11 - Contribution of crop residues incomes to cereal incomes in a dry year (%)

		Normal year	Good year	Dry year
N	Valid	27	27	17
	Missing	13	13	23
Mean		16.86	12.79	5.53
Median		15.51	9.86	.00
Minimum		0	0	0
Maximum		76	68	37

For most farmers, direct incomes from straw sales and grazing rent are not high enough to pay off production costs related to residue i.e. straw bales packing and stubble ploughing (Table 12). Direct incomes from residues exceed production costs for 40% of respondents in normal years, 25% in good years and 12.5% in dry years. Again, the circumstances of farmers are heterogeneous, since some farmers earn up to 256,420 MAD (> 25,000 USD). In contrast, numerous farmers lose, or in reality invest in livestock, more than 10,000 MAD.

Net margin from cereal residues in a normal year is significantly correlated to the stocking rate (-0,477). This correlation is logical, since, for farmers who own little cropland and a high number of animals, residues are primarily and almost entirely dedicated to animal feed. There is no apparent correlation between crop residues incomes and other variables such as summer stubble ploughing, height of straw cut, proportion of stubble retention or straw storage capacity.

Table 12 – Net direct incomes from crop residues (MAD.year^{-1})

		Normal year	Good year	Dry year
N	Valid	40	40	40
	Missing	0	0	0
Mean		8550.250	2393.525	-899.000
Median		-687.500	-3018.750	-615.000
Standard deviation		33311.626	42961.436	9280.980
Minimum		-18000.0	-41520.0	-19080.0
Maximum		170820.0	256420.0	46258.0

Conclusion of the first result

Practices relating to crop residues management are the outcome of historical evolutions caused by two major shifts: the land rights and agricultural policies entailed by independence and the catastrophic droughts in the 1980's. Inter-annual variability of cereal residues yield is extremely pronounced. Droughts have considerably renewed the importance of straw and stubble. This importance mainly translates into indirect benefits through livestock feeding, even though some direct benefits are noticeable. Nevertheless, practices, uses and direct incomes remain highly heterogeneous amongst farmers.

3.2 Agro-ecological aspects of residues retention

This part refers to the second sub research question: *"What are the potential agro-ecological on-site benefits and drawbacks of crop residues use as soil cover?".* We first explore how positive and negative effects of crop residues retention have been characterized in academic literature (with a specific focus on experiments carried out in Sidi El Aydi, INRA experimental station in Chaouia); before investigating context-specific results, enabling conditions and limitations.

3.2.1 Agro-ecological benefits of residues retention

Abundant literature has investigated the positive effects of no till with residues retention on a range of intertwined soil physical, chemical and biological properties.

Soil organic matter (SOM)

Crop residues are "the greatest source of soil organic matter" (Tisdale et al., 1985, *in* Turmel et al., 2015). "Crop residue contributes directly to SOM and its decomposition is the initial stage in the humus formation process leading to C storage" (Figure 7) (Turmel et al., 2015).

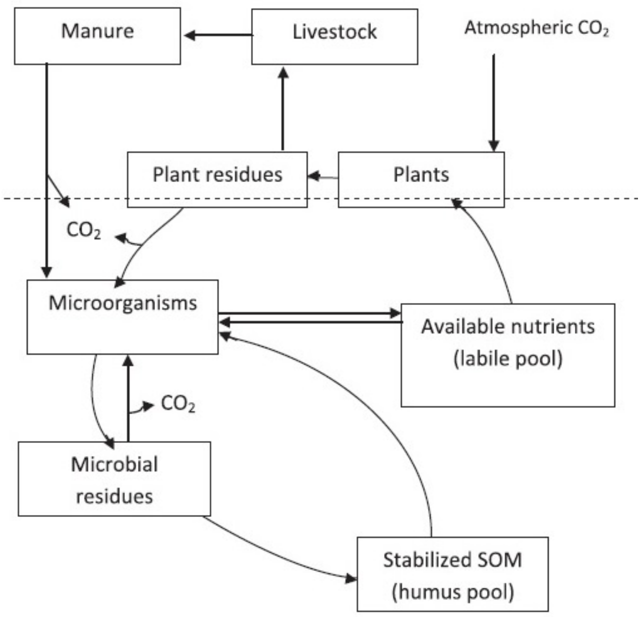

Figure 7 – Simplified model of plant residue inputs transformed by microorganisms (Turmel et al., 2015)

Table 13 - Effects of tillage and residues management on SOM % (Belmekki et al., 2013)

Soil depth	CT	NT_{50}	NT_{100}
0-5 cm	2.52	3.08	3.36
5-10 cm	2.45	2.68	3.00
10-15 cm	2.12	2.46	2.60

These assertions are verified in experiments led by Belmekki et al. in Sidi El Aydi (2013). The retention of residues adds SOM to all soil layers (Table 13). 100% retention increases SOM significantly in topsoil compared to 50% retention. At 10-15 cm, there is no statistically significant difference between the two levels of residues retention.

Soil chemical indicators

Crop residues have a major influence on Soil Organic Carbon (SOC) increase (Turmel et al., 2015). According to Turmel et al. (2015), the scope of this influence depends on soil types, climate conditions and management factors (tillage incorporates residues SOC in deeper layers while C concentration is higher in topsoil under no tillage). Crop residues also have an effect on topsoil pH, Cation Exchange Capacity (CEC) increase, N concentration and P adsorption blocking (Turmel et al., 2015). Most chemical benefits of residues are impaired in deeper layers, while tillage allows to some extent the distribution of SOC in the soil profile.

Mrabet et al. (2012) report that in Moroccan drylands N content of soil surface (0-5 cm) increases linearly with increased residues retention.

Furthermore, it is to be noted that crop residues retention enables CO_2 sequestration in soil but also contributes to mitigating CO_2 emissions by making stubble ploughing unnecessary.

Soil biological indicators

Soil biodiversity is enhanced by residues cover. Soil fauna (e.g. earthworms), microbial biomass and microbial activity (including mycorrhiza) are stimulated thanks to improved nutrient and water availability, as well as aggregate stability and cooler temperature (Turmel et al., 2015). Benefits tend to be higher if residues are retained on the surface rather than incorporated by ploughing (which causes physical harm and disturbs earthworms' habitat).

Soil physical indicators

Soil structure & aggregates stability

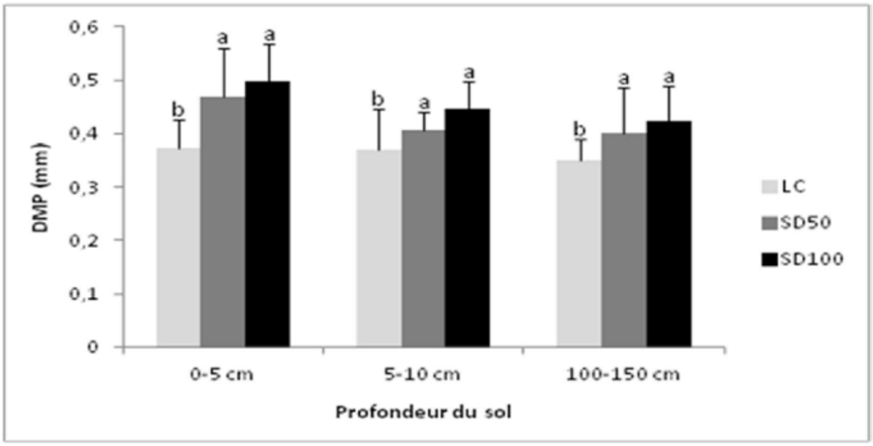

Figure 8 - Effects of tillage and residues management on aggregates stability (Belmekki et al., 2013). Soil depth in cm; DMP = mean weight-diameter (mm); LC = conventional tillage; SD50 = no till with 50% retention; SD100 = no till with 100% retention

High crop residue biomass on the surface helps improve soil structure and aggregation. Soil aggregate stability is enhanced thanks to the addition of SOM in the topsoil and the splash buffering by residues (Turmel et al., 2015). Nevertheless, some authors claim that tillage plays a more determining role (Turmel et al., 2015). Residues incorporation by stubble plowing, for instance, reduces soil aggregation, due to higher residue mineralization. However, experiments in Chaouia (Sidi El Aydi) showed a significant improvement of soil structural stability under no till and residues retention compared to no till without residues (Moussadek et al., 2011). As shown in Figure 8, the percentage of residues retention, whether 50 or 100%, doesn't have a decisive influence on aggregate stability (Belmekki et al., 2013).

Erosion

Allmares and Dowdy estimated in 1985 that 30% of cover would reduce erosion by 80% (quoted in Giller et al., 2009). Infiltration rates are closely related to soil cover (Turmel et al., 2015). In Chaouia, Moussadek et al. (2011) noticed a linear increase of infiltration with the quantity of residues retained. 50% residues retention could reduce runoff by 70% and soil losses by 50% (Moussadek, 2012). Moussadek et al. (2011) also conclude that no-till without soil cover is susceptible to accelerate runoff compared to conventional tillage (Figure 9).

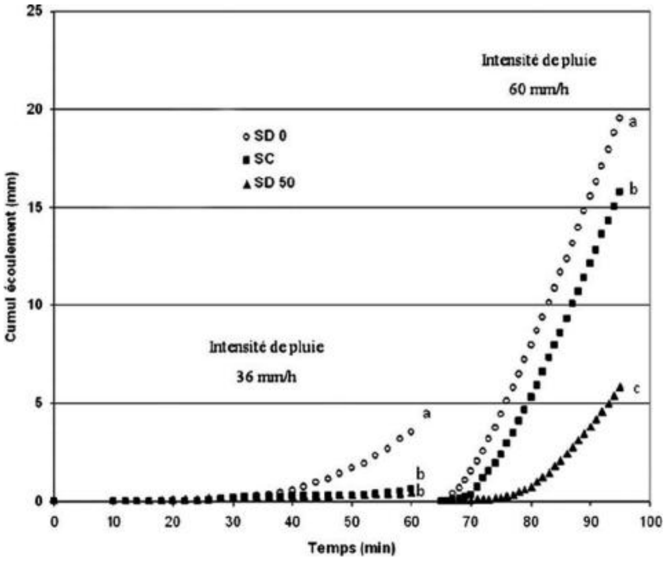

Figure 9 - Effect of 2 rainfall intensities on accrued runoff (Moussadek et al., 2011). SD0 = no till, no retention; SC = conventional tillage; SD50 = no till, 50% retention.

Soil moisture

By slowing down run-off and reducing evaporation, no tillage and crop residues retention allow soil moisture content increase (Turmel et al., 2015). The magnitude of impact is more pronounced during droughts (Verhulst et al., 2011). Tests conducted by Belmekki et al. in Sidi El Aydi station (2014) demonstrated a better soil moisture content with 50% retention compared to no till without residues retention in all soil layers (Figure 10).

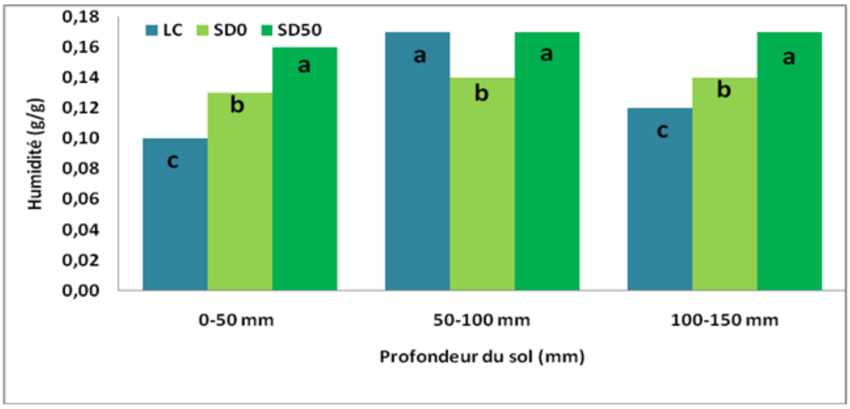

Figure 10 - Effects of tillage and residues management on soil moisture (Belmekki et al., 2014). LC = conventional tillage ; SD0 = no till & no residues retention ; SD50 = no till and 50% retention; soil depth in mm

Soil temperature

Residues cover decreases daytime soil temperature, which is beneficial for plant growth in hot climates (Turmel et al., 2015).

3.2.2 Agro-ecological drawbacks of residues retention

The picture of the benefits from crop residues retention depicted in the previous paragraph must be mitigated with a number of shortcomings implied by this practice one should pay attention to.

In the first years after retention is applied, crop residues can temporarily immobilize N during the decomposition process (Giller et al., 2009), due to an increased C:N ratio caused by cereal residues (Ichir et al., 2002).

Moussadek (2012) notices a higher density in top soil layers under residues retention, which could reduce water infiltration to the deeper layers. This is compensated for by better aggregate stability and water retention capacity, though.

Turmel et al. (2015) note a risk of evaporation of light rainfall intercepted by residues, in semi-arid areas. Similarly, residues may intercept residual herbicide, which in turn could affect weeds control (Midwood et al., 2011).

Moreover, as crop residues retention requires less grazing, land may be deprived of some services given by animals. No or minimum grazing imply less N supply from animal manure, less superficial tillage and straw decomposition by animal trampling, and less weeds control (Midwood et al., 2011).

In addition, most researchers agree on the fact that conservation agriculture is susceptible to stimulate weeds growth, particularly before sowing. Yet, documenting to what extent weeds expansion is attributable to no till only or also to residues retention is needed (Valbuena et al., 2012).

Finally, retaining more residues on the surface may challenge technical operations carried out by farmers. As observed by INRA in Smaala and Beni Khirane, a thick biomass layer is susceptible to cause seeder clogging, although the use of a mechanized seeder is vital in no till system. Further to this, depending on its height and volume, stubble may block the passage of machinery in rows (Midwood et al., 2011).

3.2.3 Learnings from Moroccan experiences

Crops productivity under residues management systems

Most experiments with residues retention come to the conclusion that, overall, residues retention improves yields, compared to conventional farming and no-till farming with residues removal. However, experiments also show that the advantage of yield under residues retention is neither absolute nor stable.

In Morocco, Mrabet conducted a long-term experiment from 1994 to 2002 in Sidi El Haydi (Chaouia), in conditions close to those encountered in Smaala and Beni Khirane (average precipitation: 308 mm; vertisols and calcixeroll soils). 4 treatments were compared:

- CT = conventional tillage, cereal residues incorporated
- NT_{00} = no tillage, cereal residues removed, 10-15 cm stubble
- NT_{50} = no tillage, 50-60% flat residues retention, 10-15 cm stubble
- NT_{100} = no tillage, 100% flat CR retention,10-15 cm stubble

Table 14 – Average grain and biomass yields ($t.ha^{-1}$) under different tillage and residues treatments, and comparison between treatments (Mrabet, 2011)

Treatment	Grain		Biomass	
	Yield	Comparison	Yield	Comparison
CT	1.90	-	5.87	-
NT_{00}	2.10	CT: + 10%	6.23	CT: + 6%
NT_{50}	2.21	CT: + 16%; NT_{00}: + 5%	6.52	CT: + 11%; NT_{00}: + 5%
NT_{100}	2.21	CT: + 16%; NT_{00}: + 5%; NT_{50}: 0	6.71	CT: + 14%; NT_{00}: + 8%; NT_{50}: +3%

Plots under no till with full residues removal gave a grain yield on average 10% higher than those in conventional tillage (Table 14). This advantage has been validated by the conservation agriculture project in Oued Zem region. Retaining residues brings a further step in yield improvement. With 2.21 $t.ha^{-1}$, the grain yield is on average 16% higher than in conventional tillage and 5% higher than in no till without retention. Retaining 100% of the residues instead of 50% doesn't make any difference in terms of grain yield, but adds 3% to the biomass yield.

In the same experiment, the grain yield in no till with 50% retention was higher than in no till with full removal for 6 years out of 8. However, it was exceeded by the yield in the conventional parcel 3 times, including 2 times in the first 3 years. It shows that on the one hand, several years are needed before seeing evidences of retention benefits; and, on the other hand, a better yield is never guaranteed in conservation agriculture, whatever the rainfalls (at least in the first 8 years).

Above-ground biomass yields show the same pattern. The yield was better in no till with 50% retention than conventional tillage or no till with no retention for 7 years out of 9. In contrast, the yield in no till with no retention was exceeded by that of conventional tillage 4 times.

Drought occurred during two years (1990-2000 and 2000-2001). After the first drought, yields were similar (0.26 to 0.28 $t.ha^{-1}$) in all the plots. The plot with no till and 50% retention treatment better resisted the second one (yield higher than that of conventional tillage by 127% for grain and 109% for residues).

Experiments conducted in other countries confirm these outcomes.

A 4-years' experiment in Peshawar region (Pakistan, loam and clay-loam soils, 200 to 760 mm) demonstrated the higher benefit from residues retention than no tillage (Mohammad et al., 2012). By retaining all the residues in two tillage treatments, the yield could be increased by 10% in conventional tillage, and 33% in no tillage on average. The yield in no till without residues was lower than in conventional tillage.

Similar results came out of a 13-years' study about a maize-wheat system in Mexico (Verhulst et al., 2011). While no till with no residues retention slightly exceeded the yield in conventional tillage, retaining residues were needed to significantly improve the grain yield. And still, the yield in no-till with residues removal was lower than that in conventional tillage with 100% retention.

Land degradation

Conservation agriculture with crop residues retention is believed to be particularly effective in erosion-prone croplands. However, we miss a quantitative insight into land degradation in Oued Zem region. Yet, we can extrapolate national data to the local conditions encountered in Chaouia-Ouardigha. In Morocco, erosion averages between 2.1 and 20 $t.ha.year^{-1}$ (Dahan et al., 2012). 52.9% of Morocco land is affected by water erosion and 17% by wind erosion (Dahan et al., 2012, data from 1992). In Smaala and Beni Khirane, the combination of moderate slope gradients and intensive land uses on marginal lands (45% of the slopes are cultivated; CANA baseline survey, 2013) suggests that this area isn't an exception to this picture.

In Morocco, overgrazing accounts for 49% of anthropogenic factors leading to erosion, and agricultural activities for 24%. Conventional tillage is believed to largely contribute to soil losses (Dahan et al., 2012). Vertisols (called *tir*), albeit the most fertile soils in the region, are prone to compaction and water erosion due to intensive use by rain-fed farmers (Moussadek, 2012). Finally, Boulal notes that the removal of windbreak trees, in Ouardigha province (merged with Chaouia since then), has aggravated the wind erosion risk (2001, unpublished).

Enabling conditions in semi-arid areas of Morocco

As underlined earlier, uncertainty characterizes the potential benefits of crop residues retention. As a result, effects of residues retention are highly spatially variable and bound to very local specificities (soil type, climate, management etc.).

Besides water, longstanding SOM decline is a structural limiting factor of cereal yields in rain-fed areas (Mrabet et al., 2012). SOM decline is estimated at 30% in Morocco between 1987 and 1997 due to intensive tillage (ICARDA/INRA, Final Report, 2015). Therefore restoring SOM in drylands soils is decisive. It has been determined that residues retention is susceptible to achieve it. Yet, Moussadek (2012) found that no-till and residues retention increase SOM significantly in Vertisols / clay soils, while the effect is neutral in other soil types (Luvisols, calcareous-magnesian). Since soils are highly diverse in Oued Zem region (INRA, Characterization of the Moroccan platform, 2015) these variable effects shall be taken into consideration. This Morocco-specific finding tending to relate SOM increase to clay content should be mitigated by other international research. For instance, it was found in Zimbabwe that, under residues retention, SOC content would much more increase in sandy soils compared to clay soils (Turmel et al., 2015).

The way residues retention is put into practice matters a lot as well. In Syria, flat residues better protect soil against evaporation; thus have more impact than standing stubble (Sommer et al., 2012). Thresholds of soil cover percentage before gaining ecological benefits must be determined at local level (Giller et al., 2009). So far, estimates have been rough. Mrabet (2011) suggests the retention of 50% of stubble. INRA researchers in Settat consider that a 30%-retention should be sufficient to achieve substantial impact.

In addition, finding technical measures to mitigate potential drawbacks related to residues retention is crucial. As conservation agriculture is susceptible to increase weeds and pests, at least in the first years after conversion, the ability of farmers to cope with this should be investigated in depth. Different alternatives should be tailored to the farmer's economic capacity (application of pre-emergence herbicides, increased labour for weeding, integrated pest management, crops rotation). As regards seeder clogging, Midwood et al. (2011) affirm that seeding machinery abiding by international standards can handle 3 to 4 $t.ha^{-1}$ of stubble. However, this is not granted in Morocco as of now, as researchers are working on developing "low-cost seeders" that would be affordable for Moroccan farmers. Lastly, the height of stubble should be controlled so as to be equal or inferior to row spacing (Midwood et al., 2011).

Conclusion of the second result

No-till without crop residues retention offers tangible agro-ecological advantages (soil health, crop productivity) compared to conventional tillage. But retaining crop residues adds further value and stability to this advantage, by correcting some of its drawbacks (compaction, runoff). Benefits of residues cover on the surface are intertwined, concern the topsoil mainly and materialize on the long run. Different experiments have demonstrated that productivity improvement is significant but temporally and spatially variable. The variability of benefits and shortcomings related to residues retentions is a factor aggravating tradeoffs around crop residues. Some studies have shown that regression between yield and residues proportion is at some point impaired, which, then, would not justify a full retention of residues.

3.3 The role of residues in the livestock system

"Straw for animals is like bread for humans" (Essayd A., Smaala, 2015)

This part answers the third research question: *"How are the equilibria and profitability of household production systems, especially livestock, altered by the adoption of crops residues retention?"*. It tackles the effects of crop residues retention on livestock feeding, and ultimately on livestock profitability, based on the economic importance of livestock and alternative feeds.

3.3.1 Importance of livestock in the household economy

Livestock vs crops

Answers to the question "What do you perceive as most important [between livestock and crops]?" (not only in terms of cash incomes) illustrate the importance of livestock and the integration of livestock and crops into one system (Chart 14). Livestock is considered more important by a bit more than half of the farmers, while 20% couldn't decide between livestock and crops. In most cases, respondents hesitated before delivering their answer.

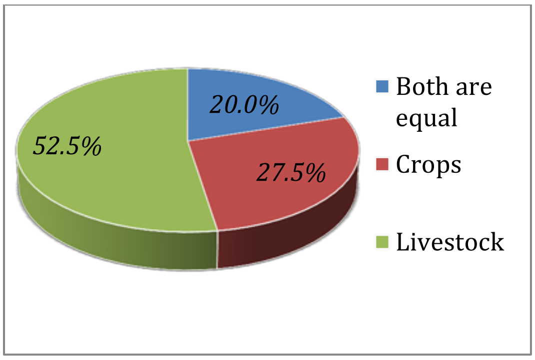

Chart 14 - Most important production system (% of respondents)

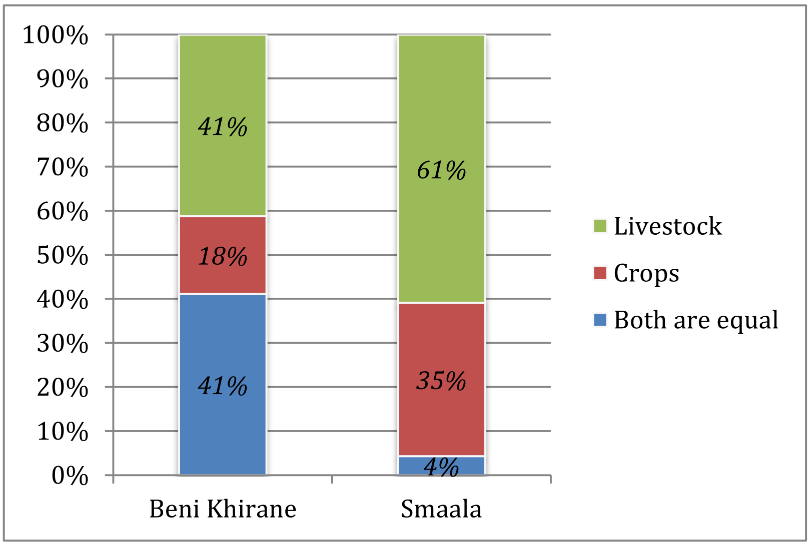

Chart 15 - Most important production system, per community (% of respondents)

Nevertheless, the result differs between the two researched communities (Chart 15). 61% of Smaala respondents gave their preference to livestock, against 41% in Beni Khirane where farmers who value livestock and crops at the same level are numerous. Paradoxically, the respondents who reported "crops" to be the most important production in the household economy own on average more animals than those who reported "livestock". In contrast, farmers who give more importance to crops cultivate 58 ha on average, against 16.5 for the livestock-oriented respondents. These characteristics tend to show that the relative importance of livestock increases commensurately to the lack of arable land. Farmers give more importance to crops once they have crossed a threshold in land area (40 or 50 ha).

Contribution to household incomes

In terms of contribution to household incomes, livestock is ranked first by half of the farmers (Chart 16). A noticeable number of farmers (42.5%) mentioned off-farm incomes (22.5% as the first source and 20% as the second source). Yet, 50% of the farmers have only revenues from crops and animal husbandry. Off-farm job opportunities in this area consist of agricultural services (e.g. tractor driver), local trade (e.g. shopkeeper), crafts (e.g. mason, painter) and public services (e.g. teacher).

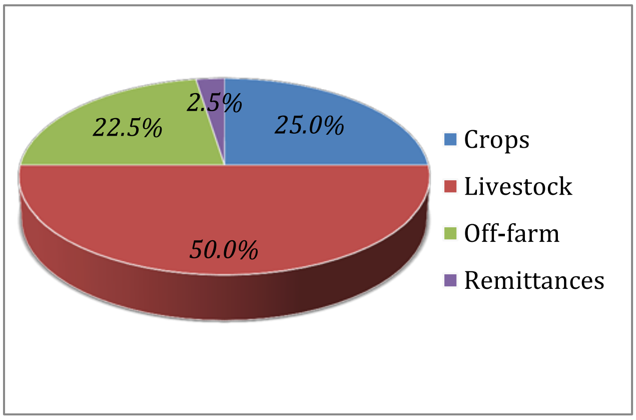

Chart 16 - First source of incomes (% of respondents)

Flock size and composition

Farmers breed on average 12.8 TLU (8.3 for the median) (Table 15). Flock size ranges from 0 to 49.1 TLU.

Table 15 - Statistics of flock size (TLU) and stocking rate (TLU/ha)

	Flock size	Stocking rate
Mean	12.75	.92
Median	8.30	.63
Standard deviation	11.71	1.16
Minimum	.00	.0
Maximum	49.10	6.2

Although in Smaala more households referred to "livestock" as the most important component of their economy, Smaala farmers own on average less livestock than in Beni Khirane (Chart 17).

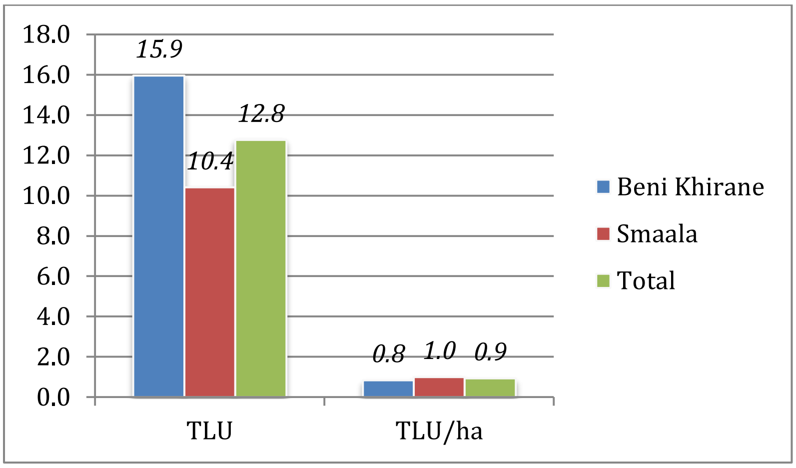

Chart 17 - Average flock size (number of Tropical Livestock Units, TLU) and stocking rate (TLU/ha)

Table 16 - Correlations between flock size and farm characteristics

Variable	Spearman correlation coefficient
Cultivated area (2015)	0.707**
Membership in farmers' organization	0.265
Land rights	0.359*
Ratio fallow-leguminous / cereals	-0.003
Tillage	0.232
Rotation	0.208
Control over crop residues	-0.296

Flock size is significantly correlated to cultivated area (Table 16). The regression between these two variables is determined by a coefficient R^2 equal to 0.5 (Chart 18). These two indicators (Spearman correlation and R^2) show that large-scale farmers tend to own more livestock. The underlying rational behind this correlation is the need of croplands to produce animal feed. This analysis must be mitigated, though. The red circle (Chart 18) points out a category of smallholders who have an important flock despite cropland scarcity. For these farmers, investments in livestock compensate for the limited potential from crops. Out of the interviewed sample, 20% of the respondents fatten lambs although they have no ewes, due to grazing availability. Hence, farmers buy lambs (about MAD 1,500 per lamb), fatten them during 3 months (about MAD 500 per lamb) and sell them before Eid festivities (about MAD 2,500 per lamb). Therefore the net profit averages around MAD 500 per lamb.

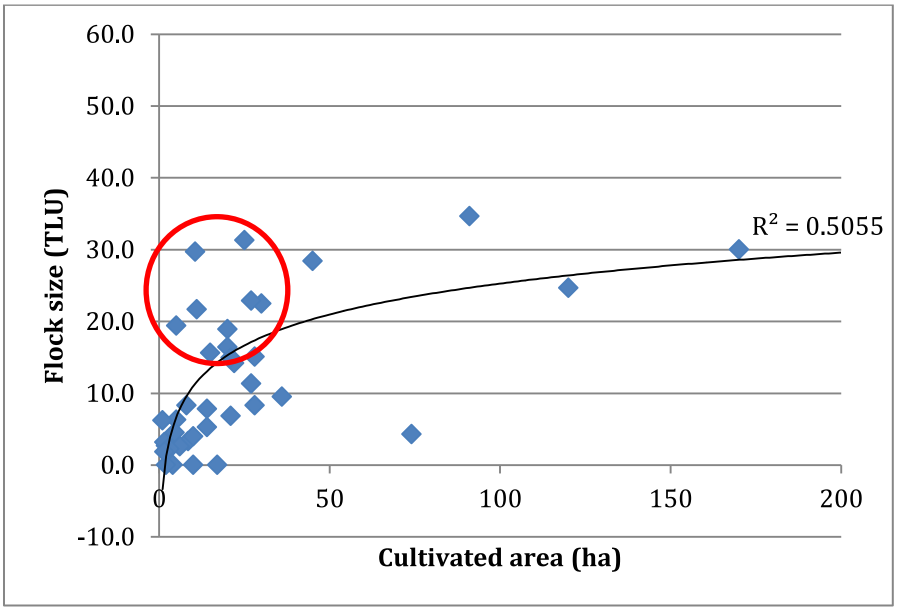

Chart 18 - Regression between flock size and cultivated area (n=39)

The relation between flock size and cropland area is also expressed through the stocking rate (TLU.ha-1). The median stocking rate is 0.64 (equivalent to 6 sheep per hectare) while the mean rate is 0.93 (Chart 17). This ratio is higher in Smaala community (smaller farms but importance of ewes and milk cows breeding).

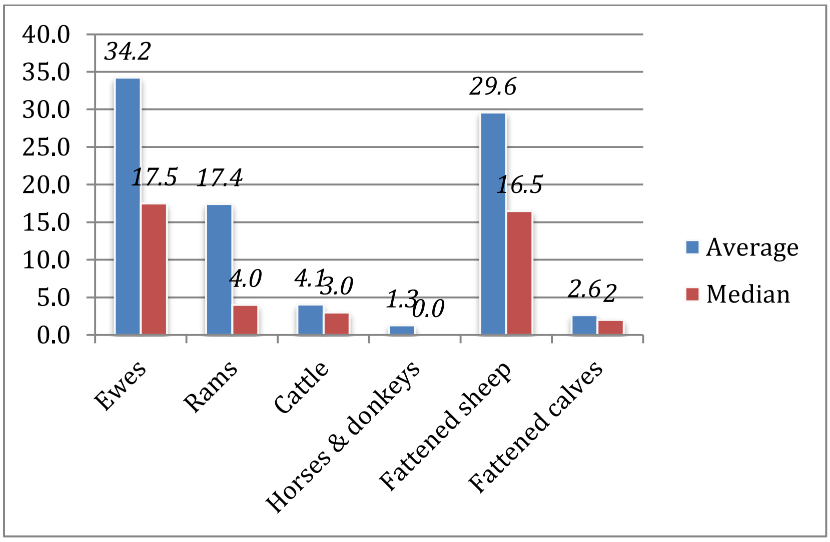

Chart 19 - Average and median number of animals per household, per type of animal

Flocks are dominated by sheep. A median farmer owns 21.5 ewes and rams, and fattens 16.5 lambs (Chart 19). 70% of farmers fatten lambs for Eid. In addition, cattle play a substantial role through calves fattening and dairy production, especially in Smaala. Moreover, some farmers breed several horses, for functional and recreational (*fantasia* events) purposes. Finally, 10% of the respondents didn't report any animal breeding or fattening in their farm.

3.3.2 Feed strategies

Feed sources

The dramatic livestock losses and the uncertainty of biomass production, both caused by the upsurge of droughts in the farmers' horizons since the 1980's, spurred them into adapting their feed strategies. This adaptation, enabled by specific governmental policies, mainly translated into the full exploitation of available resources and the diversification of feed supply.

Animal feed is usually characterized through three properties (Ben Salem et al., 2008): the fiber content, the nutrient content (especially crude proteins) and the digestibility. Basically, forage (mainly composed of stem or leaf) offer high crude fiber content, while grain and agro-industrial by-products are mostly interesting for their crude proteins content and/or digestibility.

Forage options are various: stubble grazing, straw, weedy fallow (for grazing and hay), forage from leguminous plants (peas, field bean, alfalfa, lentils; for grazing and hay), cereals fodder (barley green fodder, oat, triticale). Rangeland grazing is not an alternative anymore. Weedy fallows and forage crops are mowed in spring. After hay baling (hay will be stored with straw), animals graze the plots. Despite a certain decline of biodiversity (especially for indigenous species), caused by crops expansion, privatization and intensification, weeds density ranges between 885 and 6,192 plants per m^2 (ICARDA-INRA, Characterization of the Moroccan platform, 2015). The most common weeds and grass species are blue pimpernel, diplotaxis, common poppy and rigid ryegrass. Most weeds are eaten by animals, along with stubble or in fallow plots.

Based on our household survey, all farmers use straw for stall feeding, except a couple of smallholders who practice a rotation between weedy fallow and cereals; thus they don't have access to straw every year. In addition, 75% of the respondents fed animals with forage hay and/or weedy fallow hay. Finally, cutting barley in winter (from December to February) to collect green fodder remains limitedly practiced in Oued Zem area (Boulal, 2001).

As regards supplementation through grain and by-products, local farmers use cereal grain (mostly barley), bran and concentrates (sugar beet pulp, "cicalim"). Wheat bran and concentrates have been widely spread through subsidies since the 1980's, as an adaptation to drought risk. Like grain, bran's protein content is moderate but its digestibility is high (Ben Salem et al., 2008). Bran is used by 94% of the livestock owners. Sugar beet pulp is used by 86% of the livestock owners, while "cicalim", an industrial concentrate produced by a private company in Morocco, is used by several farmers in Smaala. Some farmers also buy maize and chickpeas. Feedblocks and oilcakes are not used in this area. The price of agro-industrial by-products is stable because guaranteed by the government, including in dry years (FGD Beni Khirane).

Farmers in Oued Zem region do not rely on only one type of feed. They try as much as possible to combine different feeds providing quantity and quality to animals – fiber, proteins and digestibility. Therefore, rations prepared during stall feeding consist of straw or hay, supplemented with grain or by-products. Similarly, grazing in harvested plots provides animals with fiber (stubble) and digestibility (residual gain) content, sometimes supplemented by additional proteins in stables. It is plausible that farmers do not quantify these properties while managing the feed calendar, but supplementation and mixed rations have become common practices since herds were decimated during catastrophic droughts of the 1980's because their animals were reliant on one source of feed (residues or weedy fallow), whose harvest happened to fail.

The distinction between marketable and non-marketable feed is worthy too. Farmers try in general to start feeding their animals with marketable feed (mainly by-products) as late as possible.

Residues for feed

In this paragraph, we look more accurately at the role of residues for feeding livestock.

In Morocco, crop residues yield 30 to 40% of livestock feed (Magnan et al., 2012). In Oued Zem, all farmers graze stubble as much as possible between the harvest and the first rains. Then, straw becomes the basis of rations in stables, throughout winter at least.

In general, stubble is more nutritive than straw, thanks to green material and residual grains left after reaping (Magnan et al., 2012). This grain (up to 600 kg.ha^{-1} in the province, according to

Boulal, 2001) adds considerable value and offers “free” nutritive feed during few weeks, in a normal year. Most studies show that grain, which is promptly selected by ruminants, disappears after one month, depending on the yield and the stocking rate:

- In Outmani et al. (1991), crude protein content in wheat stubble has declined from 4.8% at harvest time to 4.2% after 1 month and 3.2% after 12 weeks. N-rich feed is necessary from week 5, in addition to stubble and weeds. With a stocking rate between 12 and 24 ewes per hectare, half of the stubble is removed after 9 weeks, in a normal year, 140 kg of dry matter (DM) being removed from one hectare every week during the first month.
- In Guessous et al. (1989), crude protein content is 8.5% of the SOM content in the first month and 5.6% in the second month following harvest. DM falls from 3,383 $kg.ha^{-1}$ during the first month to 1,494 $kg.ha^{-1}$ from week 5 to week 10; and 773 $kg.ha^{-1}$ after week 10 (normal precipitation).
- In the experiments carried out in the frame of the ICARDA-INRA conservation agriculture project (unpublished), only 15% of stubble was left after two weeks of grazing in a normal year (unknown stocking rate). DM fell from 1,300 to 200 $kg.ha^{-1}$ in two weeks. Crude protein fell dramatically as well, from 5.6 to 9.4% right after harvest (depending on the plot), to 3.7% to 4.2% after one week and 1.9% to 4.2% after two weeks.

It is to be noted that the benefits of stubble in the first weeks after harvest are mitigated by the fact that animals expend more energy while grazing stubble, rather than being fed in stables (Magnan et al., 2012).

Straw is “deficient in many essential nutrients” (Guessous et al., 1989). Its digestible nitrogen content is low (Boulal, 2001). Nowadays, straw is never given to animals without supplementation. The FG of Smaala mentioned some effects on animal hair visible after one week in case of absence of supplementation. Furthermore, storage conditions may alter the nutritive value of straw.

In conclusion, cereal residues are rich in fiber but low in crude protein (Ben Salem et al., 2008). Stubble, after few weeks of grazing, and straw need to be supplemented.

From a farmer prospective, the interest of crop residues for feeding livestock lies mostly in the low cost, as well as the easy access of residues (chart in annex).

Feed calendar

Three categories of diet appear in the feed calendar: the diet of the flock (ewes, rams, cows), the diet of the lambs and calves fattened, and the diet of equines.

The diet of sheep and cattle, mainly determined by biomass seasonality, is not differentiated per species, race or gender. Gestating ewes do not have a specific diet, although rich feed is crucial for lambs’ health and survival rates (Guessous et al., 1989). This is related to the absence of breeding control. Rams and ewes graze the same pasture throughout the year, so reproduction periods are free and spread out over time. The sheep’ sexual activity is more hectic from May to November, or February, depending on the race (Boulal, 2001). Guessous et al. (1989) note that it coincides with the period of stubble grazing, that may be inadequate to meet ewes’ specific needs. Lambing occurs mainly from October to January (Boulal, 2001), during winter stall feeding, another sensitive period for poor livestock owners.

In a normal year, sheep and cattle graze stubble during approximately 3 months from harvest, in June (Figure 11). A minority of farmers supplement this diet with rations (straw, grain, by-products), especially after one month when stubble is very poor in nutrients. In a good year, stubble grazing may last as long as possible, until the first rains (end of October). Stall feeding starts in September-October. This is the first sensitive period for feed. Rations contain a mixture of straw, hay (forage, weeds), grain, maize, bran and concentrate, depending on the farmer’s capacity. Some farmers mentioned that rations are lowered after the first rains, at the end of fall. Flocks are sent as soon as possible to weedy fallows, from January-February.

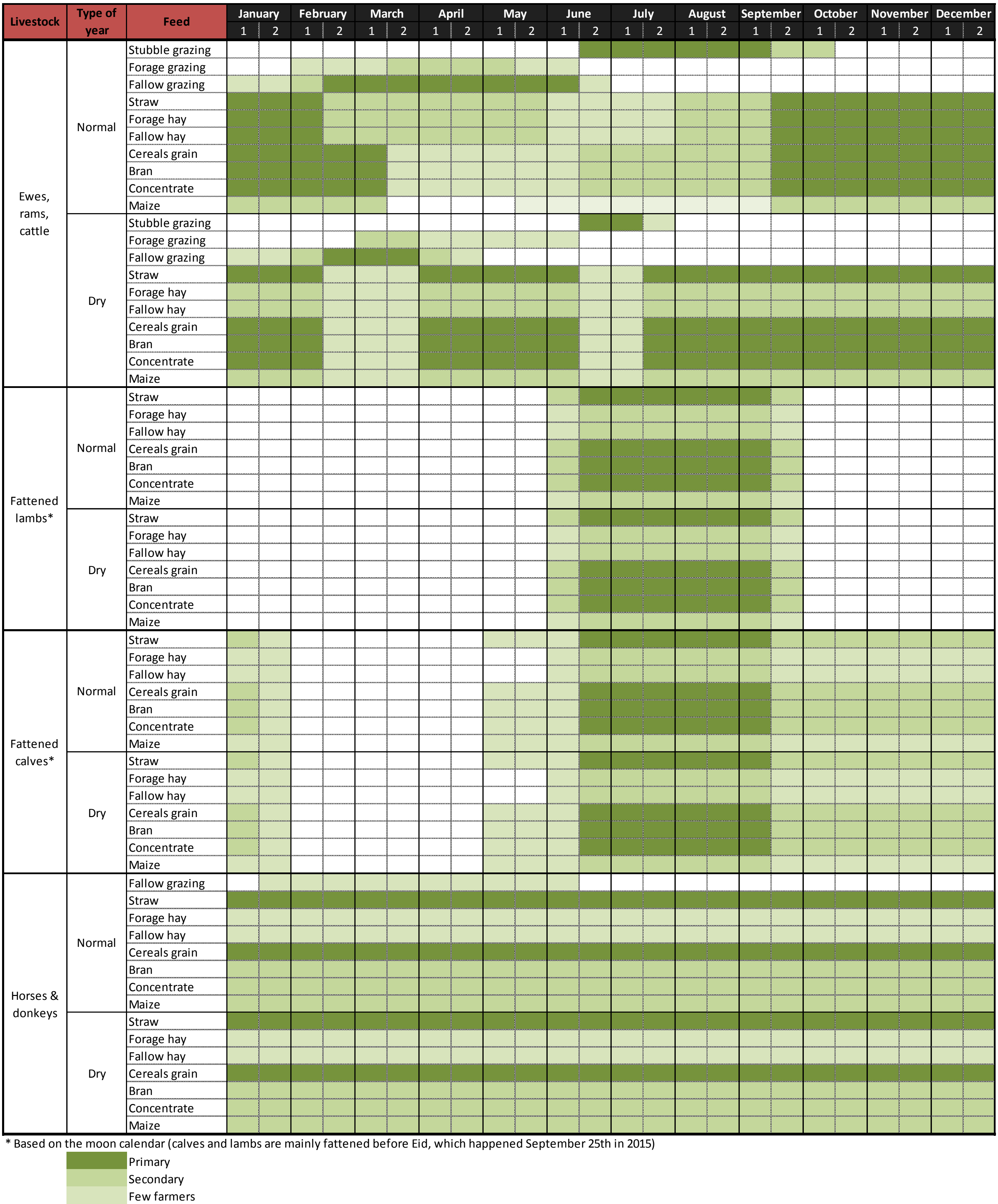

Figure 11 - Feed calendar, based on the household survey (2015)

Photo 7 – Sheep grazing stubble in Smaala (Gauny, 2015)

In a good year, flocks can graze fallow as well as forage parcels after mowing (in April), up to the cereal harvest in June. Otherwise, rations are needed. This second feed gap may last several weeks. It may be critical for small-scale farmers, as straw and grain are less available.

The diet of sheep and calves kept for fattening consists exclusively of stall feeding. Lambs are fattened during more or less 3 months and sold before Eid. Calves are also mainly fattened in anticipation of Eid, but some farmers choose to fatten calves in fall / beginning of winter too. Fattened animals receive the same rations as the flock (straw, hay, grain, by-products) but in a higher volume. For example, a farmer said that a daily ration for a fattened sheep is1.5 kg while he would give 0.5 kg of the same ration for a ewe.

Equines follow a different feed calendar. They are fed with the same ration, consisting of straw and barley grain, every day. Other elements may be added to the ration (e.g. oat, by-products). They do not graze stubble or forage residues, only few of them graze in fallow lands.

Feed strategies in dry years

The scarcity of biomass material in dry years requires adjustments in feed strategies. Changing the herd size may be a margin of adjustment (Magnan, 2015), especially for farmers who can't meet the rising need for marketable feed. Reducing the number of animals fattened or the flock size are two options quoted by farmers. Lightening the rations is another option, which can prove to be harmful for animal health though. National policies established after the dramatic droughts of the 1980's (e.g. "programme de sauvegarde du cheptel") offer opportunities to herders, such as subsidized feed distribution and by-products price stability. The effectiveness of such programs is contested by farmers, though (FGD Smaala).

In a dry year, farmers exploit available weedy fallow and stubble as long as possible. They can rely on 1 to 2 months of weedy fallow grazing at the end of winter, and 2 to 4 weeks of stubble grazing in summer (Figure 11). They face in turn two long critical feed gaps, from March to June and from August to January, where hay, stockpiled straw and marketable feed play a crucial role to keep up the flock state. The feed calendar and rations' composition of fattened animals and horses does not change in dry years.

Feed needs

Feed patterns are dominated by straw and barley grain (Table 17). Bran and concentrate form a substantial part of feed needed by livestock as well.

Table 17 - Median feed need per TLU in a normal year

Feed	Unit	Quantity
Barley grain	Kg	3,400
Bran	Kg	2,300
Concentrate	Kg	1,400
Straw	Bale	41
Forage hay	Bale	2
Fallow hay	Bale	2

Supplying barley grain in dry years is challenging. Only 27.8% of the respondents are self-sufficient after a drought. A median farmer will miss 3,25 t of barley grain to cover his yearly needs until the next harvest, unless flock size and rations change or some grain can be taken from older stocks.

Straw accounts for 57% of the forage (sum of straw, forage hay and weedy fallow hay) needed by farmers (median). Moreover, it is the sole forage for 22% of the farmers. A median farmer needs 688 bales of straw in a dry year, which is far from being covered by the harvest (median production in a dry year: 71 bales). The gap could be partially filled by straw stocked from previous harvests. However, based on our calculations (straw needed for feed and straw traded withdrawn from total straw harvested), 54% of the farmers are unable to stockpile straw bales more than a year after a normal year. Only 11% could stock enough straw to cover the gap caused by a drought.

Feed expenditure

In the end, the majority of farmers are not self-sufficient for their feed in dry years while, in normal years, they still have to procure by-products and additional grain and forage. The yearly feed expenses of a median farmer for 1 TLU (equivalent to 9 sheep) are considerable: MAD 1,446 in a normal year, MAD 4,881 in a dry year (Table 18). At farm level, a median farmer spends MAD 18,312 in a normal year and MAD 55,095 in a dry year (Table 19). These indicators illustrate how tremendous the impact of drought on the farmer's budget is.

Table 18 - Yearly feed expenditure per Tropical Livestock Unit (MAD/TLU)

	Normal year	Dry year
Median	1,446	4,881
Average	3,712	8,571

Table 19 - Total yearly feed expenditure at farm level (MAD, n = 36)

Statistics	Normal year	Dry year
Mean	27700	70956
Median	18312	55095
Standard deviation	34403	61625
Minimum	2500	1250
Maximum	167750	248028

In normal years, the main expenses related to feed consist of bran and sugar beet pulp purchase (Table 20). 27.8% of livestock owners have to buy barley grain and 22.2% spend money for straw. Maize is a significant post of expenses as well. The situation is opposite in dry years. 70 to 80% of farmers have no choice but buying barley grain and straw.

Table 20 – Yearly feed expenditure per type of feed at farm level (MAD, n = 36)

Year	Statistics	Barley grain	Maize	Bran	Straw	Forage hay	Fallow hay	Sugar beet pulp	Cicalim
Normal year	Mean	2836.11	3241.67	9500.00	1145.83	973.61	222.22	6277.78	1847.22
	Median	.00	.00	7500.00	.00	.00	.00	5000.00	.00
	% of « 0 »	72.2	55.6	5.6	77.8	83.3	97.2	11.1	86.1
Dry year	Mean	14902.25	5677.08	18216.11	14375.14	1151.17	N/A	14850.58	
	Median	10746.06	.00	10320.46	8067.39	.00	N/A	6815.12	
	% of « 0 »	27.8	58.3	8.3	22.2	85	N/A	8.3	

The number of animals fattened and sold is a relevant indicator of the livestock system productivity. The higher it is, the more scale economies (e.g. shepherds hiring, marketable feed) can be realized. Some specialists establish the profitability threshold in Morocco at 100 lambs and calves fattened for Eid (El Koudrim, personal communication).

Grazing rent

In addition to feed procurement, some farmers take out indirect expenses pertaining to crop residues production and baling (details in the first research question), shepherds hiring (for large-scale producers only, not taken into account in this study) and, for smallholders, plot rent for stubble or fallow grazing.

19.4% of livestock owners rent plots for stubble grazing and 45.7% for weedy fallow grazing (Chart 20). For stubble, a large part of farmers reach agreements with landlords to graze freely, or practice free grazing without authorization. The percentage of farmers renting parcels for fallow grazing is much higher, as free grazing is hardly applicable in fallows. Renting other parcels for grazing is a primary alternative for smallholders with important flocks. It is particularly important for smallholders who practice a rotation between cereals and fallow, because, every two or three years, they have no or little fallow in their farm. The payment of fallow grazing rights is logically correlated to the stocking rate (Table 21): those who are in this case have an average stocking rate of 1.7 $TLU.ha^{-1}$ against 0.9 $TLU.ha^{-1}$ for the whole sample. Similarly, it is negatively correlated to the cultivated area. Furthermore, those who have stronger land rights and practice no till seem to be less subject to paying fallow rights. The average ratio fallow-leguminous / cereals of those who pay fallow rights is 34% (against 29% for the whole population), meaning that these farmers already dedicate a part of their farm to weedy fallow or forage crops.

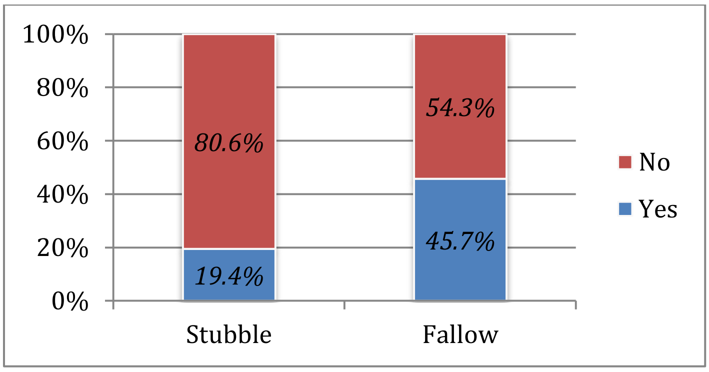

Chart 20 - Payment of stubble and fallow grazing rights (% of livestock owners, n = 36)

Table 21 - Correlations between payment of fallow rights and farm characteristics

Variable	Spearman correlation coefficient
Cultivated area (2015)	-0.419**
Land rights	-0.330*
Ratio fallow-leguminous / cereals	0.087
Tillage	-0.317*
Rotation	-0.142
Flock size (TLU)	0.04
Stocking rate (TLU/ha)	0.787**
Unconsented grazing	-0.162

Farmers rent 2 to 2.5 ha for grazing, on average. Determining the price of grazing rights is the fruit of an informal negotiation, but generally speaking farmers respect tacit rules. In Smaala, 1 hectare is rented MAD 250 for stubble grazing and MAD 1,000 for weedy fallow grazing (FGD Smaala, 2015). The value of weedy fallow is enriched by its proteins content and the presence of wild onions whose market value has recently increased.

3.3.3 Robustness of feed alternatives

Given the role of residues in livestock feeding, the retention of more residues on the ground surface could be adopted by farmers only if they find feed alternatives. Different options are worth considering: purchase of marketable feed (especially by-products); expansion of weedy fallow; forage crops cultivation (forage mixtures, fodder crops); and other hybrid variants (ley farming, alley-cropping). In this paragraph, we rule out any alternatives relying on the substitution of market feed to residues: since the attractiveness of residues lies in their low cost, in the farmers' eyes, it is unlikely that a majority of farmers would simply give up this resource and significantly increase their feed expenses (Magnan, 2015). Other options consisting of grazing in remote pastures (e.g. remainder of Smaala forest, south of the researched area) are not considered either, due to advanced land degradation and specific land use rights in this area (Boulal, 2001). Therefore, we will mainly look into what has been tried during the CANA project in terms of forage crops (forage mixtures, fodder crops, alley-cropping). The project made the assumption that traditional weedy fallows are not productive enough, whether in terms of quantity and nutritional quality. Hence, farmers should add value to natural fallows or grasslands by cultivating forage crops. It seems that this vision has been re-evaluated at the end of the project, after the benefits of traditional weedy fallows have been appraised more accurately. In consequence, weedy fallow with improved management (fertilization, treatment of undesirable species) could be an alternative to be explored in the future (CANA, Final Report, Annex 14, 2015).

Biophysical and economic performances of forage alternatives

Forage mixtures

Different forage mixtures, consisting of associating of forage crop (forage pea, vetch) and a cereal (barley, oat), were tried during the CANA project, under no tillage (CANA, Final Report, Annex 14, 2015). The primary objective of associating forage and cereals was to improve the quality of the feed. Other forage mixtures (e.g. barley-medicago) had been tried by INRA in the 1990's (CANA Platform Characterization, 2015).

Peas and barley are locally produced, but were never associated before project (Photo 8). Vetch is naturally adapted to shallow soils and dry conditions but the exogenous vetch variety sown proved to be not adapted to the local circumstances. Oat, which was introduced in the province in the mid-1990's, is adapted to semi-arid conditions (yield up to 2.2 t.ha^{-1}, Boulal, 2001). Triticale is also dry-tolerant and easy to grow.

Photo 8 - Pea-barley mixture in a farmer-managed trial (CANA Final Report, 2015)

The vetch-oat mixture turned to be the most productive one in terms of the grain yield. But in terms of the biomass yield, the pea-barley mixture (75% of pea, 25% of barley) gave the best results (up to 7 t.ha^{-1} of dry matter). Its crude protein content (6.03 to 12.95% without glyphosate, 9.89 to 15.4% with glyphosate application, depending on the trials) exceeded that of stubble after harvest. It was also determined that native weed species contributed to improving significantly the N content in the soil as well as forage quality.

It was concluded that the adoption of a pea-barley mixture could improve the livestock performance by 30% and decrease the dependence on markets for feed by 70 to 80% (Boughlala et al., 2015a). Based on the trials, the pea-barley mixture should be mowed later March – early April, which would extend the winter feed gap (compared to weedy fallow) but with very nutritive hay making in return.

Fodder crops

In addition, the CANA project implemented trials with fodder crops (oat, barley and triticale) in monoculture, under no tillage. The results were in general higher than cereals cultivated with conventional tillage. As regards grain production, barley and triticale gained the highest yields (in 2014: barley = 1.1 $t.ha^{-1}$, triticale = 0.85 $t.ha^{-1}$, oat = 0.6 $t.ha^{-1}$). In terms of the fresh matter yield, oat produced 10 $t.h^{-1}$, twice that of local barley and triticale. In this respect, oat could be an interesting feed alternative to barley & wheat crop residues. With a better dry-tolerance at the end of the cycle (CANA Final Report, Annex 14, 2015), triticale could be a solid alternative in case of drought or seasonal rainfall variability.

Alley-cropping

Alley-cropping is another alternative for feeding livestock. It was tried by INRA-ICARDA in two farms during two years. In this agroforestry system, forage trees or shrubs are planted in rows with crops grown in alleyways between the rows. Rows of trees and shrubs bring multiple benefits: N fixing, soil conservation, feed production, shelter effect limiting evapotranspiration, and windbreak. This system is particularly beneficial in period of drought. Mixing shrubs (e.g. *atriplex*, cactus) and trees adds value (Ben Salem et al., 2008). The association of *Atriplex nummularia* and cereals or forage has demonstrated clear results in Moroccan drylands (CANA Platform Characterization, 2015). *Atriplex* leaves are appreciated by livestock; their yield ranges from 0.3 to 1.2 $t.ha^{-1}$ (Boulal, 2001). In the CANA frame, the presence of *atriplex* ensured a +25% increase of crop yield, in normal and dry years.

Alfalfa

Planting alfalfa (*Medicago sativa*) instead of leaving weedy fallow is another option for improving feed production. Ecotypes of spontaneous *medicago* are already widespread in fallow (Boulal, 2001). However, non-perennial alfalfa is less dry-resistant than forage peas. There is also a risk of infestation of the next crops (El Koudrim, personal communication).

Ley farming

Alternatively, ley farming could be considered. It consists of alternating grain sowing and grassland/fallow in a multi-year pattern. *Medicago* (or other forage crops) could be sown alternating with fallow (CANA Platform Characterization, 2015).

Farmers' attitude to feed alternatives

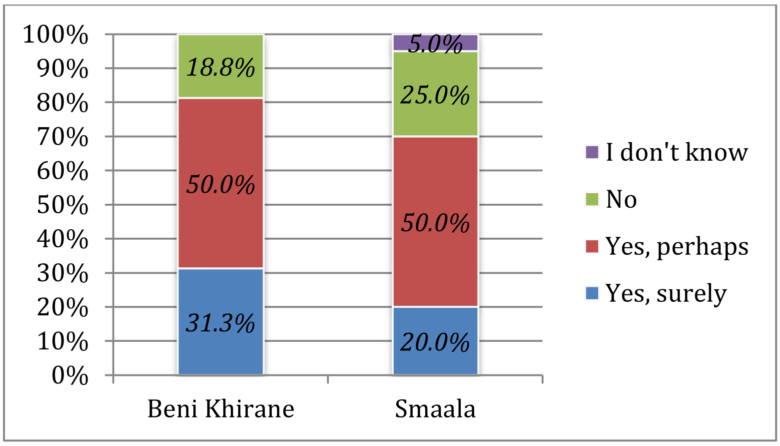

Chart 21 – "Will you start or expand forage alternatives in the future?" (% of respondents)

Before the conspicuous and documented benefits of diverse feed alternatives, the farmers of Smaala and Beni Khirane are in general favorable to these options (principally forage mixtures). 25% said that they will "surely" start (or expand, for the early adopters) forage mixtures in a near future, and 50% said that they will "perhaps" do so (Chart 21). The "perhaps" can be interpreted as an indicator of persisting doubts and a call for external support (technical and financial). In total, 37.5% of the respondents are already cultivating forage crops (mixtures or monoculture) and 7.5% do not produce forage hay but buy it.

Those who express a stronger interest in forage alternatives (e.g. forage mixtures) are those who have more land and more livestock (Table 22). However, those who claimed livestock as their most important production system are susceptible to be more reluctant to forage crops (negative correlation, -0.329*), which is a very sensitive problem to be addressed by future projects. The correlation with tillage is significant (0.415**), meaning that the farmers who have already experimented the no till system are more prone to forage alternatives, which is logical since no till and forage mixtures constitute the package brought to farmers by INRA and ICARDA. Interestingly appears a significant correlation between attitude to forage alternatives and barley straw yield: it could mean that increasing straw yield would bring more security to livestock owners in terms of feed.

Table 22 – Correlations between attitude towards forage alternatives and farm characteristics

Variable	Spearman correlation coefficient
Farmers' organization membership	0.152
Cultivated area (2015)	0.395*
Land rights	0.369*
Ratio fallow-leguminous / cereals	-0.097
Tillage	0.415**
Barley grain yield in a normal year	0.131
Barley straw yield in a normal year	0.361*
Flock size (TLU)	0.542**
Stocking rate (TLU/ha)	0.225
Number of fattened sheep	0.396*
Feed expenditure in a normal year	-0.223
Most important production system	-0.329*
Control over crop residues	0.117

Most farmers recognize the better quality of forage hay compared to straw (FGD Smaala). Some are also aware of the benefits of rotations involving leguminous crops for soil health and crops productivity. However, they also stress a number of constraints (Chart 22, "Constraint #1" = first constraint; "Constraint #2" = second constraint).

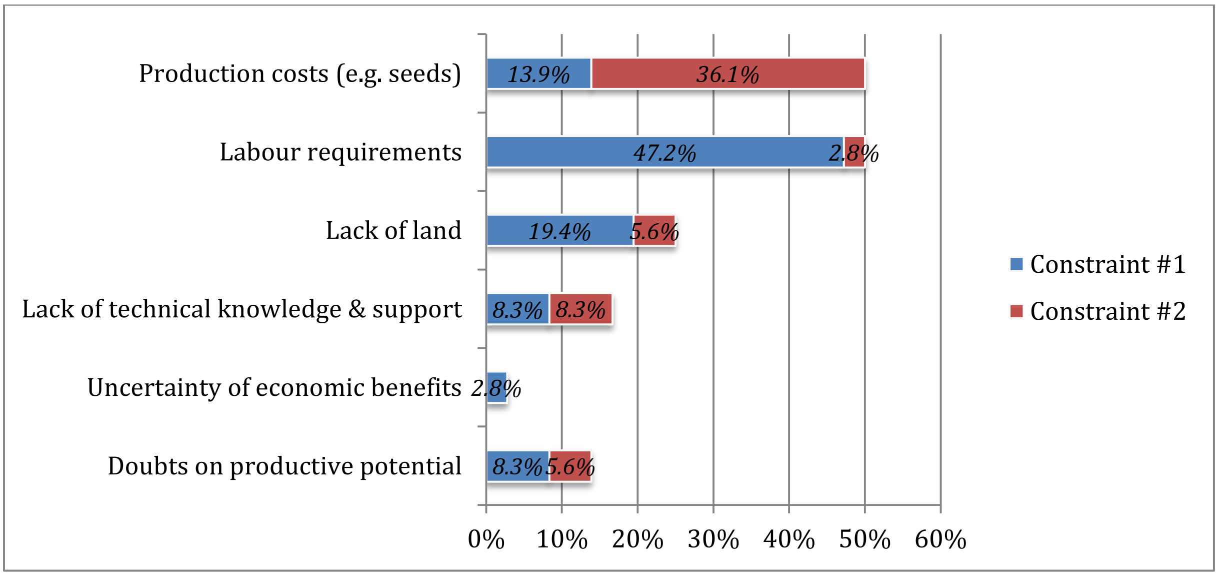

Chart 22- Constraints to forage alternatives adoption (% of respondents, n=36)

The first constraint lies in the increased labour requirements, caused by the lack of mechanical harvesting techniques for forage crops (CANA Platform Characterization, 2015). Availability and affordability of qualified manpower are critical barriers to cultivation of forage crops. The bales packing work is meticulous and slow: a daily worker can pack only 3 bales of forage hay per day (FGD Smaala). His/her wage is more or less MAD 100 per day. With a yield of 300 bales per hectare, a farmer should spend more or less USD 1,000 in hay baling for one hectare. In comparison, we have seen previously that the bales packing cost for straw is around USD 50 per hectare. Those who refer to the labour shortage as the main constraint have on average more family workforce available (2.5, against 2.2 for the whole population) – perhaps is their system less mechanized. Further, maintenance is also a concern in alley-cropping system. Boulal notes that in Oued Zem region, despite good results, many alley-cropping systems were badly maintained or abandoned after few years (2001).

The production costs are the second constraint to forage crops cultivation. Beside labour costs, the installation of forage crops entails important costs (seeds, fertilizers, seeder) compared to weedy fallow. For instance, forage pea seeds are on average 3 or 4 times more expensive than cereal seeds (El Koudrim, personal communication), irrespective of the fact that some species and varieties are currently not available on local markets (e.g. vetch). Production costs are seen as the main constraint by a number of large-holders, who may perceive some difficulties to scale-up forage crops at farm scale. The CANA project appraised the costs and benefits of forage mixtures in no-till system, in comparison with weedy fallow (Boughlala et al., 2015b). The costs inflation (+ 97%) was outweighed by the surplus in benefits. In the end, the net profit is 81% higher in forage mixture than in weedy fallow.

The lack of land emerged as the third barrier to forage crops expansion (25% of the respondents). Those who claim lack of land as a major barrier to forage alternatives uptake indeed own less land than the average (7.6 ha on average). But this argument underlines the state of mind of a lot of farmers vis-à-vis forage crops: these should not substitute but add to cereals. This conservative perception, although not shared by all farmers, may be quite concerning regarding the capacity of farmers to (re-)think the production system, where crops and livestock are integrated, as a whole.

Some farmers, a minority of them, still have doubts on the productive potential of forage crops, especially in dry years. It was reported that triticale is less beneficial to the animals' nutrition (FGD Smaala). More broadly, technical assistance from extension services is expected by farmers, so as to optimize the potential of forage crops, and make the conversion profitable. In addition, management practices and inputs (e.g. vetch variety) should be tailored to match local characteristics (climate, soils, biodiversity).

In conclusion, addressing the costs of forage production and bridging the knowledge gap are decisive steps to validate forage crops as a sound alternative to cereal residues. National policies of subsidies for forage cultivation could unlock the potential of this alternative (Ben Salem et al., 2008). But nowadays, policies (e.g. Green Morocco Plan) tend to support cereals intensification and make any alternative (unless 'out of the box', e.g. orchards) hardly competitive with cereals. It also touches on the problem of forage crop, and more generally, by-products pricing (Ben Salem et al., 2008). Finally, the large adoption of forage crops might also leverage livestock expansion (FGD Beni Khirane), which might in turn conflict with the principles of sustainable agriculture.

3.3.4 Simple costs and benefits analysis of residues partial retention

Design and limits

Anticipating the costs and benefits of residues retention could give rise to a full study. Direct effects of residues retention on crop yields are not accurately known, yet. The way residues are retained (e.g. flat or standing, % of soil cover or mulch thickness) and the influence of context-specific factors (e.g. soil type) entail important variations. Furthermore, temporal variability of the retention impact (e.g. soils) as well as management (e.g. rotation) and exogenous (e.g.

precipitation, markets) factors make it necessary to observe the effects of this measure on the long run (at least 10 years), by using a model.

However, we proceeded with a simple calculation of benefits and costs balance (Table 23, more details in the Methodology part) which gave a first insight on the potential benefits of retaining residues. We aligned the economic calculations with the parameters used in Mrabet' experiment (2011), consisting of the full retention of stubble (10-15 cm high) and the retention of 50 to 60% of flat residues (i.e. straw).

Table 23 - Synthesis of costs and benefits of residues partial retention

Costs	Benefits
From residues retention	*From cereal yield increase*
Decreased straw sales	Increased grain production/sales
No incomes from payment of stubble grazing rights	Increased straw production/sales
From changes in management practices	*From changes in management practices*
Increase in fertilizers and herbicides use	Decreased straw baling costs
	No stubble ploughing costs
From the conversion of cereals to forage	No payment of stubble grazing rights
Decreased grain and straw production/sales	
Increased seeds costs	*From the conversion of cereals to forage*
Increased labour costs	Decreased expenses in fertilizers
Increased baling costs	Decreased expenses in chemical products

Many parameters were ruled out of this estimation: inter-annual variability of precipitation (only the data of a normal year were integrated), time needed for the accomplishment of residues' positive effects, cost of social enabling conditions for residue retention (e.g. fencing, watchmen, increase of stubble shadow value), indirect benefits of retention (animal health, farming system intensification), other opportunity costs and functions pertaining to livestock grazing (e.g. nutrient cycling, payment of shepherds).

The estimation was carried out with the pea-barley mixture as a feed alternative, the forage mixture being cultivated in a certain area formerly used for cereals. The same analysis could be done with other forage alternatives, such as weedy fallow expansion and/or improvement. The analysis should be conducted with lower levels of residues retention (lower percentage, or only stubble).

Hints and first lessons learnt

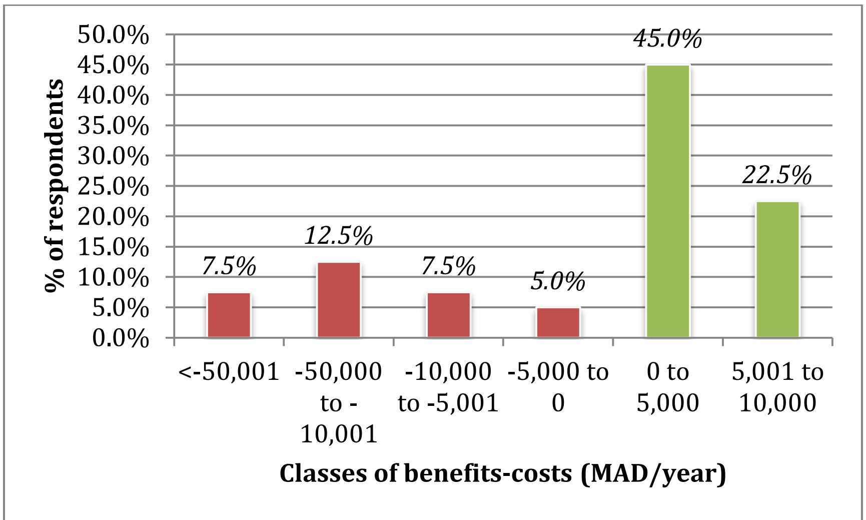

Chart 23 - Benefits-costs balance of partial residues retention at farm level (% of respondents)

As expected, the profitability of partial residues retention is undecided and contrasted (Chart 23). However, the results of this rapid analysis show a surprisingly significant domination of farmers for whom the adoption of this radical measure would be profitable (67.5% in total). This is surprising because this management of residues implies finding an alternative to 100% of stubble and 50% of straw, which could seem insurmountable. Yet, the profit is extremely reduced: 45% of the farmers would earn up to MAD 5,000 (USD 500) per year at farm level compared to a no-till system with residues removal; and no farmer could claim a profit increase exceeding MAD 10,000. Unlike these farmers, retaining such an amount of residues would be extremely harmful for some categories of farmer, the straw sellers, who could lose more than MAD 50,000 (more than USD 5,000) per year.

Benefits are mainly stimulated by the increase in grain sales enabled by yield rise (+6,600 MAD/year for a median farmer) and the decrease in baling costs. As, in this system, straw is primarily dedicated to soil cover, farmers wouldn't benefit much from residues yield increase. As regard the costs, the substitution of forage crops to a part of cereals deprive farmers of substantial incomes. The erosion of straw sales capacity dramatically affects large-scale crop producers. In contrast, the extra forage production costs described above (labour, seeds) account for a minor part of the costs specifically generated by this retention pattern.

The analysis of correlations (Table 24) allows a finer insight on the profile of the potential early adopters (demonstrated profitability) and laggards (loss-making measure). Large-scale farmers, who also happen to have larger flocks in general, are less susceptible to generate profits thanks to residues retention. The correlations are in general significantly negative with variables illustrating the importance of residues in the generation of direct incomes ("net incomes from crop residues", "contribution of residues to cereal incomes", "% of straw traded"), which is more relevant to large-scale crop producers. For those, the agro-ecological benefits of residues retention are outweighed by the dramatic loss of incomes from straw. Moreover, the correlation with the ratio fallow-leguminous vs cereals is significantly positive: it confirms that cereals-oriented farmers would be disadvantaged by residues retention, unlike farmers who already have a noticeable leguminous production or practice weedy fallow. In general, smallholders for whom benefits from residues are mostly indirect (livestock feeding) would find more opportunities with forage growing by utterly changing their feeding system. The stocking rate is not a factor specifically correlated to the profitability of residues retention.

Paradoxically, those who tend to have a favorable attitude to conservation measures (and who happen to be mainly educated middle- to large-scale cereals-oriented farmers) wouldn't benefit from residues retention. The correlation with the attitude to increasing forage alternatives in the future is significantly negative. Moreover, the profitability of residues retention is not specifically correlated to variables encompassing best practices ("% of stubble left on the soil"), knowledge ("residues retention benefits scoring") and attitude to residues retention ("acceptable crop residues retention level").

Table 24 – Correlations between benefits-costs balance of partial residues retention and farm characteristics, residues management and attitude to conservation practices

Variable	Spearman correlation coefficient
Cultivated area (ha)	-0.573**
Ratio fallow-leguminous / cereals	0.440**
Net incomes from crop residues in a normal year	-0.408**
Contribution of residues to cereal incomes in a normal year	-0.428*
Flock size (TLU)	-0.493**
Stocking rate (TLU/ha)	0.261
Feed expenditure in a normal year	0.305
Stubble left on soil in a normal year (%)	0.104
Straw for stall feeding in a normal year (%)	0.365*
Straw for trade in a normal year (%)	-0.508**
Height of straw cut	0.095
Increase in forage alternatives in the future	-0.404**
Knowledge of crop residues retention benefits (score)	-0.079
Acceptable crop residues retention level	-0.288

Conclusion of the third result

The integration of livestock and crops into one farming system, articulated around the role of residues as feed, is demonstrated by the regression between these flock size and cultivated area, even though a class of smallholders with large flock should be looked at separately. Livestock is considered more profitable in general, and more secure in case of drought, thanks to feed diversification since the 1990's. However, farmers are far from self-sufficient for feed in dry years, and partially in normal years.

Although stubble and straw account for the major source of feed in specific periods of the year, their importance should not outshine that of weedy fallow and forage crops. These two constitute promising alternatives, with significant potential for adoption even though labour intensity in forage growing is an important constraint which will hinder spontaneous dissemination, but could be overcome through awareness-raising.

The picture of benefits-costs entailed by partial residues retention is contrasted but unexpectedly positive for a majority of farmers. Nevertheless, the fragile economic advantage of this system suggests a narrow room for adoption, and requires anyhow finer calculations.

3.4 Attitude to conservation agriculture and decision-making

In this part, we touch on the fourth research question: *"How do the farmers' perception of and experience with conservation agriculture, and land rights, shape potential decision to invest in crop residues retention?".* We first look at drivers of decision-making, before characterizing the farmers' attitude to no till and residues retention. We end this part with land and grazing issues.

3.4.1 Decision-making

Grasping why the farmers do what they do helps anticipate if and how they could adopt conservation agriculture. Farmers' decisions are driven by know-how, experience, perceived risks, expected returns, importance of farms in household economy, markets, policies (Tittonell et al., 2015). Therefore decision-making is also influenced by non-rational and subjective factors (Kessler, 2006).

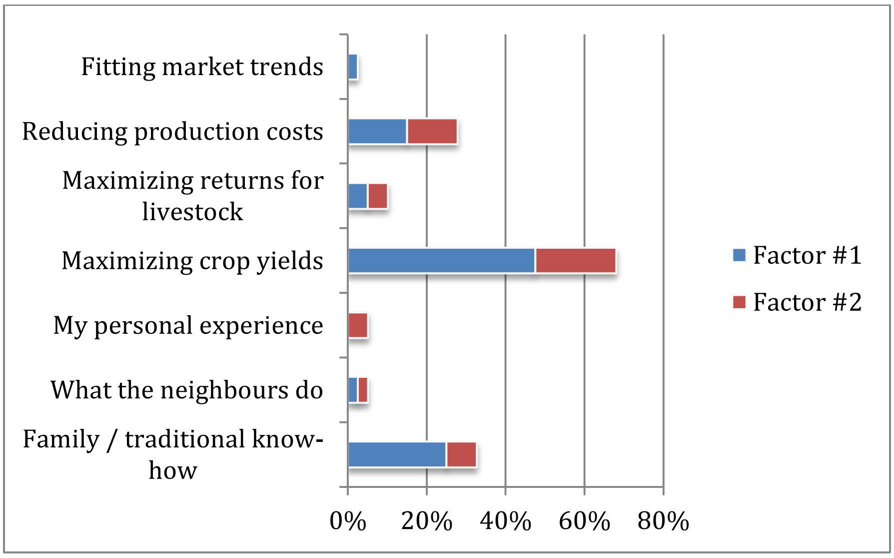

Chart 24 – Ranking of decision-making factors (% of respondents, first and second factors)

The first decision-making factor for Smaala and Beni Khirane farmers is a positive objective, consisting of "maximizing crop yields" (Chart 24), that is to say, increasing agronomic performances. This decision-making factor largely outweighs the "maximizing returns for livestock" factor. This could seem contradictory with the greater importance of livestock in the production system, as expressed by the respondents (0). There is no doubt, however, that livestock incomes would benefit from maximized crop yields. Since livestock is a more secure resource since the 1990's, reducing risks of crop failure and increasing crop production, that will in turn benefit the whole system, is an important adjustment variable to farmers.

"Family / traditional know-how" and "reducing production costs" are the two other factors driving farmers' decisions. The first one underlines the weight of conservatism. An example illustrates it. Three brothers in Smaala run the family farm. They told us in the interview that they would like to try no tillage but they don't dare because their father is rigorously opposed to this. The importance of "reducing production costs" exemplifies the dependence on agro-inputs (e.g. machinery, seeds, chemicals) and the instability of net margins. Very few farmers mentioned the market as a driver of change in farm management (e.g. adoption of newly high-pricing species).

We can derive from this picture some lessons for conservation agriculture adoption. Any new management practices should have a clear effect on crop yields while contributing to decreasing production costs, which can be achieved by conservation agriculture. Pronounced awareness-raising is necessary to overcome psychological and social barriers.

3.4.2 Attitude towards no tillage

No-till is a prerequisite to residues retention. The farmers' attitude to this practice indicates the gap towards residues retention could be bridged.

Towards adoption

No till management system has been brought to the farmers from 2012 on. The technology is still evolving (e.g. seed drill). It is too early to talk about true 'adoption', as it implies continued use without incentives. However, the attitude of farmers involved in the no-till project, their willingness to expand no-till beyond the trial plots, and the spontaneous uptake of this technology by other farmers are an indicator of adoption potential.

The CANA project focused on a limited number of farmers for trials (30 in theory). The team faced difficulties to find farmers interested in trials at the beginning of the project (11 in the first year). Further, the rate of withdrawal in the course of the project was significant, as it was in another CA research in Morocco (Schwilch et al., 2015). Many farmers of the project didn't practice no tillage outside the trial plot. At the end of the project, 45% of the farmers planned on keeping on practicing no-till (Boughlala et al., 2015a). It shows how challenging and long the adoption of no till will be.

Nevertheless, encouraging signs have been recorded. Almost 1 farmer involved in trials out of 2 has developed a strong motivation in no till and will continue without incentives (Boughlala et al., 2015a). Some farmers planned on spontaneously starting no till in few parcels in 2015-2016. During the last year of the project, 290 ha were cultivated under no tillage by 30 farmers. A dynamic has been triggered. The better resistance of no till plots to the drought in 2013-2014 contributed to raise the interest of more and more farmers. Some converted the whole farm in 2014-2015.

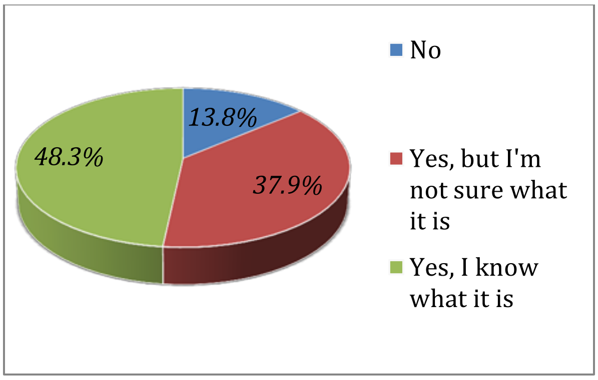

Chart 25 - "Have you heard of no-till?" (% of farmers who practice conventional tillage)

The adoption potential is backed by a growing visibility of no-till amongst the rural population, which was an underlying objective of the project. Only 13.8% of the interviewees don't know what it is (Chart 25). However, a significant part of the farmers didn't know exactly how it works.

The profile of no-till farmers is distinctly differentiated (Chart 26). So far, no till seems to be a technology for large-scale farmers. Farmers who are in a mixed system grow 36 ha and own 15.8 TLU on average, against 29.8 ha and 11.4 TLU for farmers in conventional tillage.

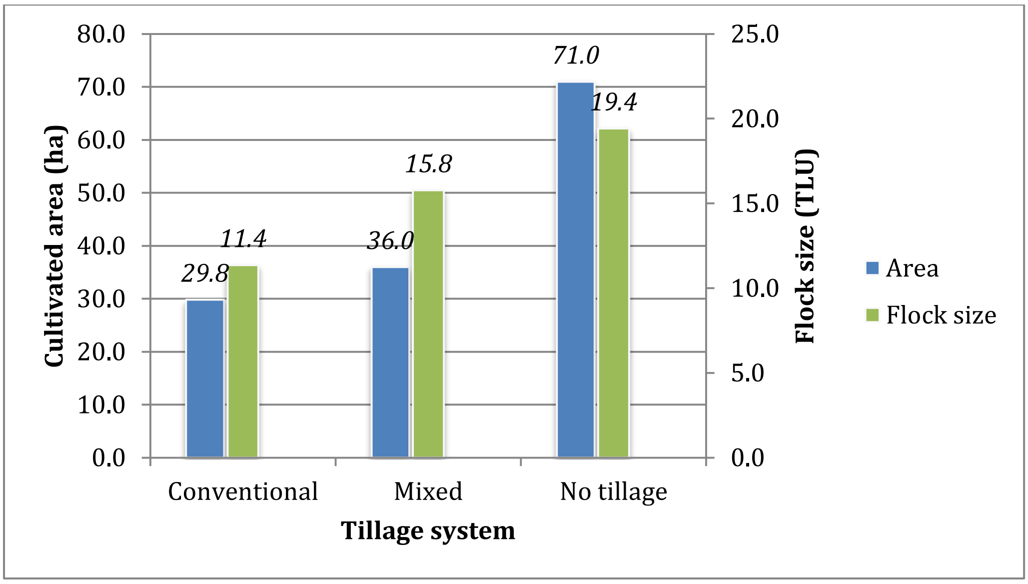

Chart 26 - Average cultivated area and flock size per tillage system

Constraints

The relatively low proportion of respondents who reported doubts on the benefits of no-till for soil and plants (23.7%) is a sign that the majority of farmers has noticed and does not contest the advantages of the no-till system (Chart 27).

The lack of availability of the no-till seeder is claimed by 42% of the respondents to be the primary constraint to the uptake or expansion of no-till The availability of the seeder is limited by the sowing date (no-till farmers are encouraged to sow more or less at the same date, early in the season) and the ongoing efforts done by INRA to tailor the seeder to the local agro-ecological and financial circumstances. Parallel to its availability, the seeder cost is another hindrance to no-till dissemination. Since imported seeders are unaffordable to farmers (16,000 to 20,000 USD)and no-till seeders are in general insufficiently subsidized by the government (ICARDA-INRA, CANA Final Report, 2015), it seems necessary to propose a locally-produced low-cost seeder (5000 to 8000 USD for the 2 models made by INRA), which requires further R&D.

Beside bottlenecks related to seed drills, 52.6% of the interviewees admitted being limited by a lack of knowledge around this innovative practice and a lack of technical support. Decades of belief in the necessity of ploughing soils cannot be reversed without sustained investments in capacity building. In addition, messages promoting tillage still spread by the Ministry of Agriculture do not help clear up farmers' confusion and doubts (El Gharras, personal communication).

The anticipated increase in herbicides and fertilizers costs appears to be a secondary constraint, which should be carefully addressed though. More broadly, weed control can be problematic to farmers under no-till, especially in small- to middle-size farms (Boughlala et al., 2015a).

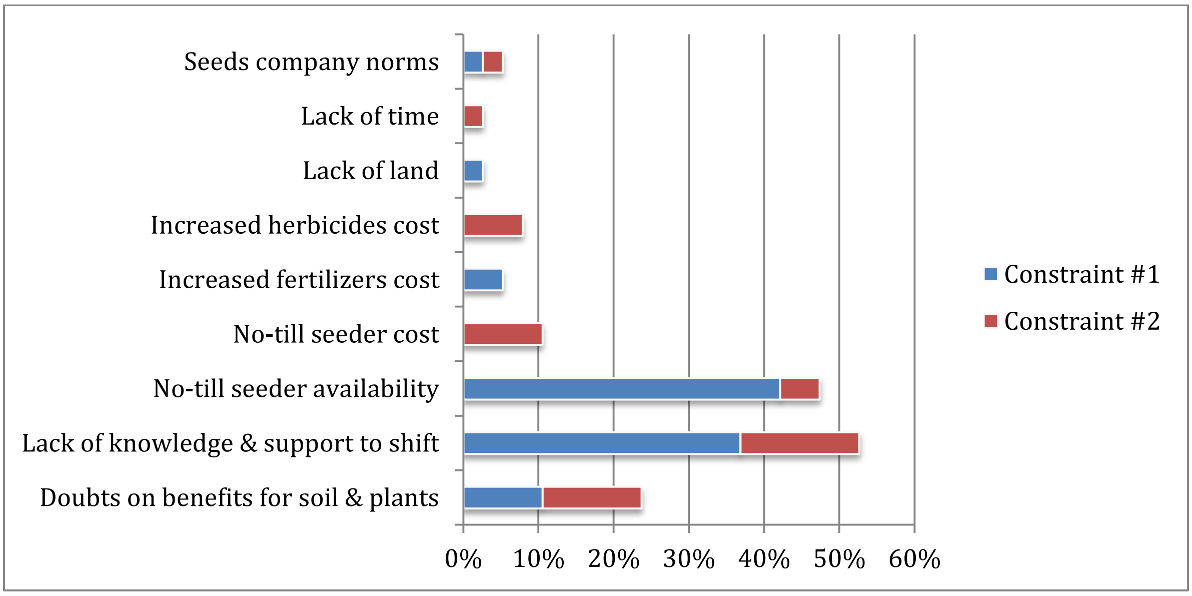

Chart 27 - Constraints to no-till uptake (conventional farmers) or expansion (farmers in mixed system) (% of respondents, first and second constraint)

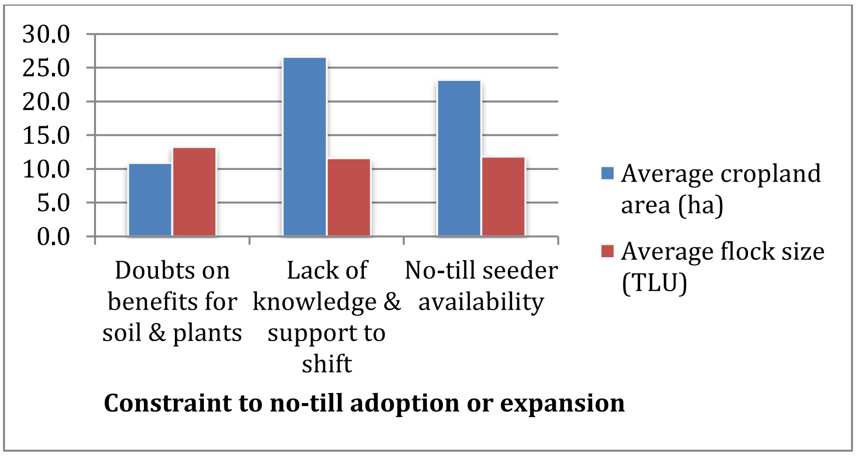

Chart 28- Farm characteristics of respondents based on the first reported constraint of no tillage

The perception of no-till constraints varies according to the farm characteristics. Farmers who express more doubts with regards to potential benefits of no till tend to be smallholders (11 ha on average) who have a bit more livestock than farmers referring to other barriers (Chart 28). Medium to large-holders, seemingly more convinced by no-till, are now in demand of support (technical and material, through the no-till machinery) to allow the conversion. Hence approaches to no-till popularization should be adapted accordingly.

3.4.3 Attitude towards crop residues retention

Perception of residues retention benefits and shortcomings

Some farmers are aware that keeping more residues on the surface is possible. Some interviewees mentioned that they have seen other residues retention in other Moroccan regions (e.g. Kenitra, not semi-arid) or countries.

The majority of farmers recognize the agro-ecological advantages of residues retention (Chart 29). A farmer of Smaala who owns no livestock (Chouqi M.) keeps more biomass on the ground throughout the dry season: he is convinced that he has a better grain yield than his neighbors. In the FGD held in Smaala, participants acknowledged the better yields obtained thanks to higher residues retention in another participant's farm. At parcel scale, 60% of respondents admitted that, when more residues are left on some parts of the soil (even not on purpose), the yield is bettered the year after (Chart 29). For instance, when the baler leaves thicker residues mulch in windrows, the farmers notice the benefits for the next year's yield.

75 to 80% of the interviewees agreed on the statements referring to the benefits in terms of soil properties (organic matter, moisture, structure). The benefits in terms of erosion control are less largely shared, due to less sensitivity to erosion. Finally, the statements pertaining to the opportunity for reducing labor needs and costs (less straw bales packing, no stubble ploughing) were not acknowledged at all. It is plausible that, farmers, on the one hand, cannot realize all the implications of a practice which is not applied in the area, and that some, on the other hand, consider activities around residues management necessary and not optional. This should be further explored, as experience shows that there is more adoption of measures allowing money saving (e.g. no tillage) than measures allowing opportunity costs saving (Fleskens et al., 2013).

The perception of retention benefits is not significantly correlated to any variable.

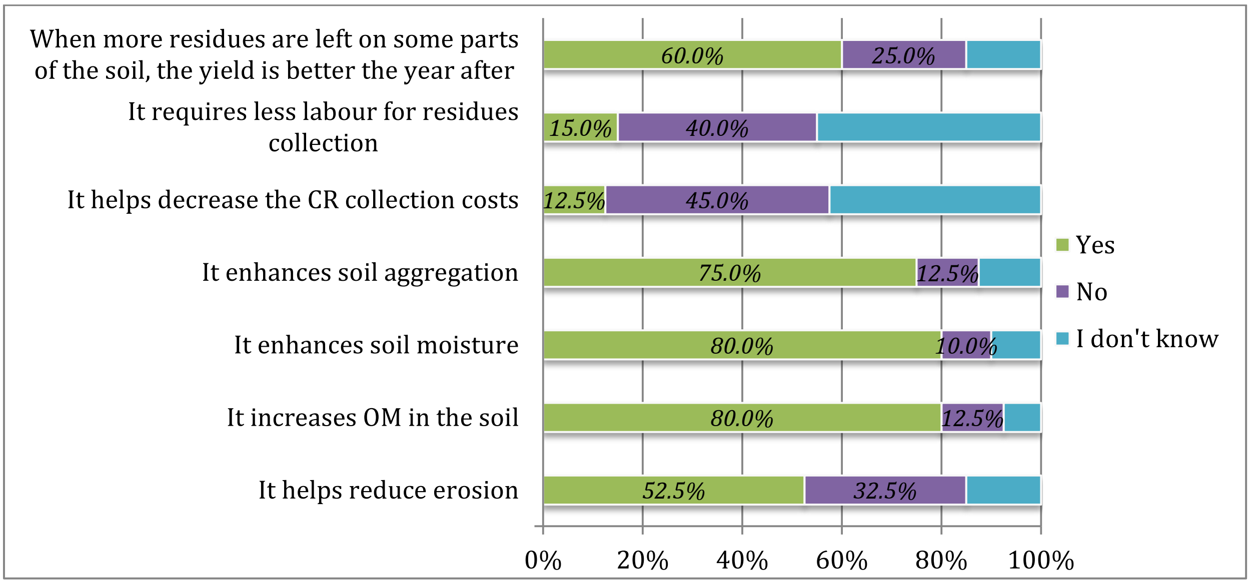

Chart 29 - Perception of crop residues retention benefits (% of respondents)

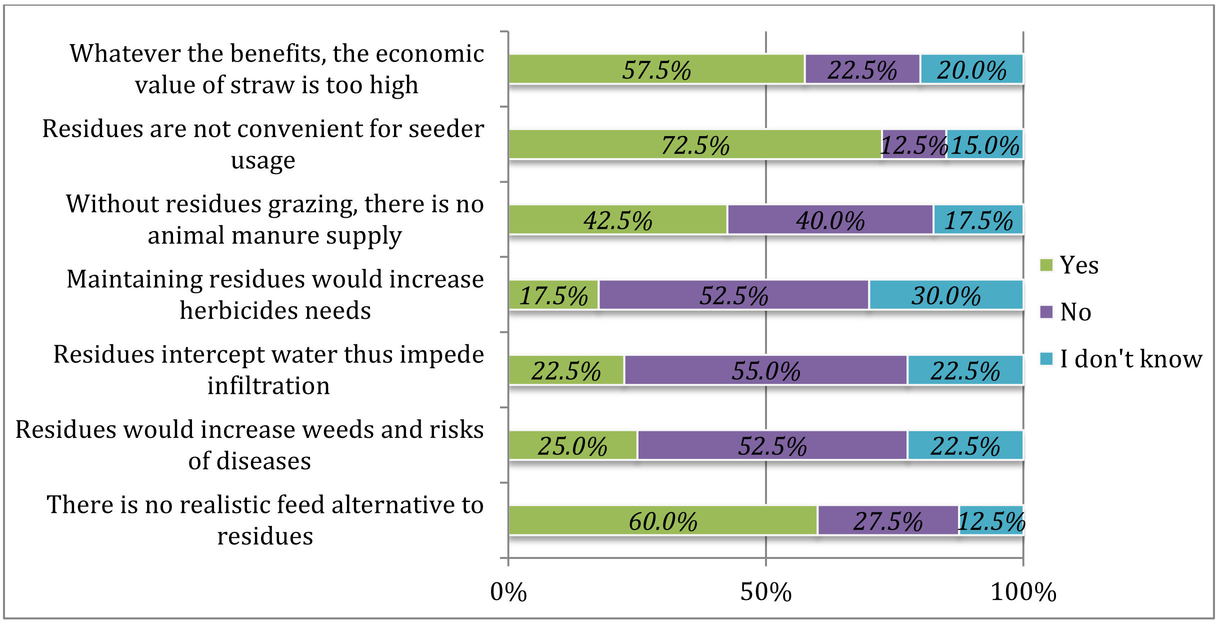

Chart 30 - Perception of crop residues retention shortcomings (% of respondents)

Disadvantages of residues retention are variously acknowledged by farmers (Chart 30). Respondents do not particularly fear any increase in weeds and herbicides needs, probably due to lack of experience and knowledge. The shortage of animal manure supply is admitted by 42.5% of the interviewees. The problems of seeder clogging caused by the thickness of biomass left on the surface, especially in low cost models, are more widely admitted (72.5%). In the FGD, some participants mentioned specific problems of wheat yellowing in places where more residues had been left (probably due to N deficiency). Moreover, straw left on the soil is susceptible to be removed by wind (FGD Smaala).

The importance of residues for feeding livestock remains the main barrier in the farmers' mind. 57.5% think that "whatever the benefits, the economic value of straw is too high". And 60% agree on the statement "there is no realistic feed alternative to residues". The latter mitigates the generally positive attitude towards forage alternatives analyzed in the third result. At this stage, the attractiveness of forage alternatives is too weak to counterbalance the importance of residues.

Finally, beliefs firmly rooted, such as the necessity of a clean surface before sowing or the benefits of incorporating residues into the soils, which were mentioned by several farmers, shouldn't be under-estimated.

Acceptable level of retention

After interviewees were asked to determine which approximate percentage of stubble retention they would agree to, the picture is mixed (Chart 31). 25% would accept to retain up to 30% of their stubble, and 17.5%, more than 30%. These ones could form a solid basis of early adopters. In contrast, 20% of the respondents remain reluctant to leave any residues on the surface and 30% wouldn't leave more than 15% - which corresponds on average to what is actually left now in a normal year.

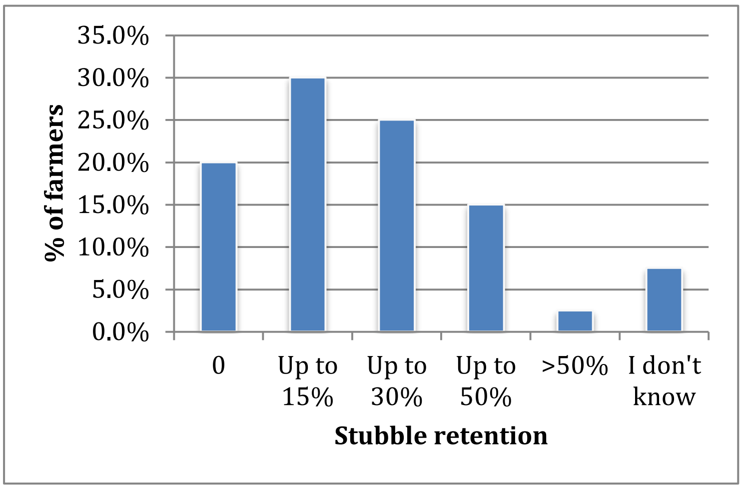

Chart 31 - Acceptable level of stubble retention (% of respondents)

Looking at explanatory variables, the propensity to increase residues retention is not particularly related to household wealth (flock size, cropland area). It is not correlated either to the actual amount of stubble left on the soil, which suggests that this practice is not intentional. Interestingly, a negative correlation with the total feed expenditure in a normal year (-0.330*) stresses the fact that those who are not self-sufficient in terms of feed in a normal year, notably due to lack of straw, are particularly not interested in retaining more residues. There is no significant relation between the attitude towards residues retention and the involvement in the CANA project, which shows that a gap of awareness needs to be bridged.

3.4.4 Land and grazing issues: an impediment to crop residues retention

Beyond possible shortcomings of residues retention, farmers appear to be concerned by the feasibility of such a measure, in relation to grazing issues, which are themselves embedded in specific land tenure systems.

Stubble grazing issues

As a legacy of pastoralist communities, stubble has always been considered a "common property resource for grazing" in the plateaus and plains of Central Morocco (Magnan, 2015). Based on religious and custom rights, water and grass are traditionally free of use, although French colonization and post-independence governments introduced the concept of privacy. Stubble use is limited to the farmers from the community (or tribe) while use intensity is unregulated (Magnan, 2015). Grazing is mainly free: we have already seen that only few farmers pay rights for stubble grazing while a lot of livestock owners do not ask permission before grazing stubble. Unconsented grazing is accentuated in dry years, when the feeding value of stubble is enhanced (FGD Beni Khirane).

The situation differs between the two communities: unauthorized grazing is a common practice in Beni Khirane while it is more regulated in Smaala. In Beni Khirane, 76.5% of the interviewees reported problems of unconsented grazing, against 39.1% in Smaala (Chart 32).

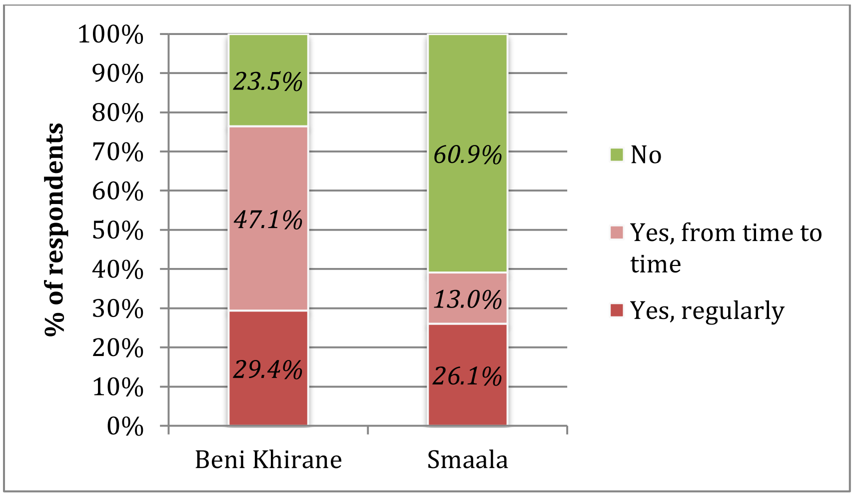

Chart 32 - Experience of unconsented grazing from other livestock owners after harvest (% of respondents)

Overcoming this grazing issue is a thorny problem, for different reasons.

First, agreements between landlords and livestock owners are not easy to settle. In some cases, land owners allow some neighbors or relatives to graze freely on their property. These agreements are particularly common in Smaala, where tacit rules are in general upheld, although FGD participants also reported unauthorized grazing by night or when the land owner is away.

Second, there is little room for complaints. Most farmers who witness unauthorized grazing on their land adopt an attitude of avoidance. Farmers don't want to generate problems with their neighbors (FGD Beni Khirane). This attitude is fueled by the inter-connection between middle- to large-scale crop producers and livestock-oriented smallholders. Landlords need these smallholders to work as daily workers at hectic phases of crop production (e.g. straw stacks making). Some cases of unauthorized grazing are brought to the court (e.g. Hicham D. in 2015), but it remains rare and it doesn't lead to any prosecution, due to insufficient evidences.

Third, even in the case of agreements, fully controlling flocks is difficult to many livestock owners, who cannot afford the payment of a shepherd. Usually, animals roam freely or are watched by kids or the head of household a part of the time (FGD Smaala). As a result, plots boundaries are frequently crossed, purposely or not.

Fourth, protecting cropland from grazing is challenging to land owners. The payment of workers to watch the property 24/24 is hardly affordable. The scattering of plots would entail important costs, while reducing labour is a powerful driver of farmers' decisions (cf. reluctance to forage mixtures). In general, more attention is paid to the plots close to the house. Consequently, remote plots, less controlled, are more exposed to free grazing. Similarly, fencing is hindered by the plots scattering and the heavy costs associated. We met one farmer who has fenced 1.5 ha for an unreasonable cost of MAD 70,000 (mesh fence). A tendency toward fencing has been observed in other areas in Morocco (Schwilch et al., 2015): it is aimed to reaffirm land ownership and protect high-value productions, which are promoted in the Green Morocco Plan (e.g. fruit trees).

Overall, farmers from Beni Khirane are pessimistic about their capacity to protect their land from free grazing (fencing or agreements), whereas this objective seems more achievable in Smaala, mainly through negotiation (Chart 33).

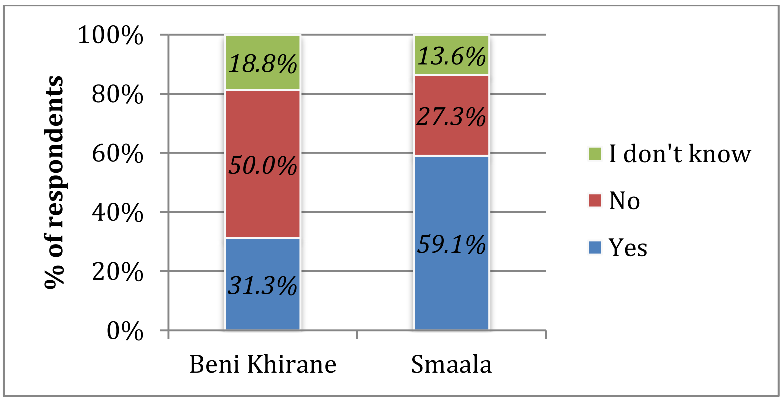

Chart 33 - "Do you think you could protect your plot from unconsented grazing?" (% of respondents, n=38)

The grazing threat influences farmers' practices. It spurs them into harvesting as quickly as possible to reduce the risk (Hicham D.). It has overall a negative impact on crop performances and soil conservation.

Crop residues retention and grazing

We can reasonably think that a farmer who would experiment or continuously adopt the retention of cereal residues wouldn't be able to control free grazing. We can expect that a dense and thick cover of residues would attract even more animals (Beuchelt et al., 2015). Crop residues retention by some better-off farmers could entail a number of social and economic changes.

Tensions between farmers and herders might become sharper. The enforcement of grazing rights on private plots would reduce feed opportunities for smallholders. It might in turn increase the livestock pressure on more marginal lands (Schwilch et al., 2015) and deepen economic inequalities among the communities.

N. Magnan conducted a number of studies on the "shadow value" of stubble in Moroccan semi-arid areas. Since a minority of farmers pays grazing rights, the value of stubble is floating and hard to determine, unlike straw. Stubble is a highly valuable resource, whose implicit value is particularly higher for small-scale farmers and in drought year (Magnan et al., 2010). He concluded that for most farmers, especially small-scale and livestock-oriented, the shadow value of stubble outweighs the benefits of adopting no tillage with residues retention (Magnan et al., 2012). Furthermore, the enforcement of property rights by a farmer reduces stubble available for common grazing, so increases the shadow price of stubble as feed (Magnan, 2015). Therefore, the adoption of retention by a small group of early adopters, supposedly better-off farmers, would aggravate the deterrent to the adoption of residues retention by the majority of farmers.

Land tenure

Grazing issues are exacerbated by land tenure inequalities in the area. These inequalities have been inherited from colonial and post-colonial times (cf. History of Land Use). Smaala and Beni Khirane are two different communities in this regard. Unequal access to land in Beni Khirane, where smallholders and poor herders cohabit with large-scale farmers, fueled heterogeneity of the population in terms of livelihood, wealth and labour. Inequality and heterogeneity translate into latent tensions around land and resources. A growing number of land disputes around grazing, fencing and land use are being witnessed.

Unequal land distribution after independence, particularly pronounced in Beni Khirane, has been aggravated by inheritance rules, which have entailed land fragmentation. For instance, we interviewed a farmer in Smaala whose father owned a piece of land of 12 ha, divided into 10 children. This farmer now owns 1.5 ha. This fragmentation goes alongside land scattering, which hinders control or fencing. Nonetheless, it has been shown that land tininess is not *per se* a barrier to farm investments in Maghreb (Ngaido, 1999).

Land fragmentation also is a consequence of joint ownership, a system in accordance with Islamic law. The Islamic jurisdiction recognizes shares to all heirs (males and females) (Benhassine et al., 2008). The ownership rights are divided but not the land itself, in view of maintaining land entirety. This system doesn't facilitate land restructuration and can create complex situations, as it solicits the agreement of all sharers. More than 50% of the lands in full ownership are managed under the traditional joint ownership system in Morocco (Benhassine et al., 2008).

Inequalities of land tenure have been gradually erased by policies. According to Benhassine et al. (2008), 75.8% of arable lands in Morocco are under full ownership and full use (*melk taam*). This status is expanding at the expense of statuses of incomplete ownership (*melk naqqis,* Ngaido, 1999). The latter encompasses former collective tribal lands, religious lands (*habous*) and royal domains. In Oued Zem region, most lands had been allocated to pastoral tribes, prior to settlers-driven agricultural expansion. Since the independence, these collective lands have been titled, with or without registration. This process of "melkisation" has *de facto* offered full land use to title owners.

One could wonder if land tenure status could be a barrier to land improvement. Owners of individualized collective lands would be limited in their investments in comparison with owners in full ownership. This assumption wasn't verified by Ngaido (1999), who found a positive correlation between land tenure security and land improvement for enhanced productivity (e.g. destoning, fencing, tree planting, water harvesting). However, incomplete rights do not prevent farmers from investing, as they will get full benefits. In our survey, only 22.5% of the respondents considered their land rights a barrier to investment.

Finally, the resolution of land disputes is constrained by the duality between traditional and modern approaches. Two settlements, the Islamic law and the modern registration system, coexist (Benhassine et al., 2008). The registration settlement delivers an irrevocable and unimpeachable title. In the settlement inspired by Islamic law, ownership is recognized by two Islamic clerks (*adoul*) on the basis of testimonies by 12 witnesses. *Adoul* can in consequence establish acts for non-registered titles (Benhassine et al., 2008). In practice, 85% of notarized agreements (e.g. land inheritance, acquisition) are enacted by *adoul* in Morocco (Benhassine et al., 2008). The duality of the two systems creates a grey area that fuels confusion and disputes around land boundaries and rights. Nassif et al. (1999) reports that most disputes recorded from 1986 to 1996 related to the transgression of former collective lands, through land use (cropland, pastures) or fencing.

Conclusion of the fourth result

The increase of crop yields, if not strained by incommensurable production costs, drives potential decision of farmers to change practices. The promising results of no-till, made visible through the CANA project, have paved the way to larger adoption of this technology in the future, even though a number of constraints (seeder, knowledge gap) may be sensitive, for smallholders in particular. Advantages of residues retention are generally admitted although the economic advantages must be further put forward. The importance of residues for feed remains insurmountable until farmers are intrinsically convinced by forage alternatives. The land tenure context, characterized by inequalities in land ownership and land use, influences residues use and farm investments. The possibility that residues retention would exacerbate disputes around land and grazing shouldn't be ruled out.

3.5 Risk aversion and time horizons

This part tackles the question: *"To what extent do the farmers' risk aversion and temporal dimensions of costs-benefits influence the adoption of crop residues retention as a soil conservation measure?".* Given the timespan of residues retention effects, looking into the farmers' perception of risks, especially in terms of drought, and their horizons of planning, informs on the appropriateness of the technology.

3.5.1 Risk perception

Risk ranking

Drought is perceived as the main risk, both in terms of severity and likelihood, by 90% of the farmers (Chart 34). The climatic hazard surpasses other risks: market turmoil (most common 2nd risk), livestock epidemics, inflation & lack of availability of agro-inputs, frost and wildfire. No respondents picked land degradation or land disputes.

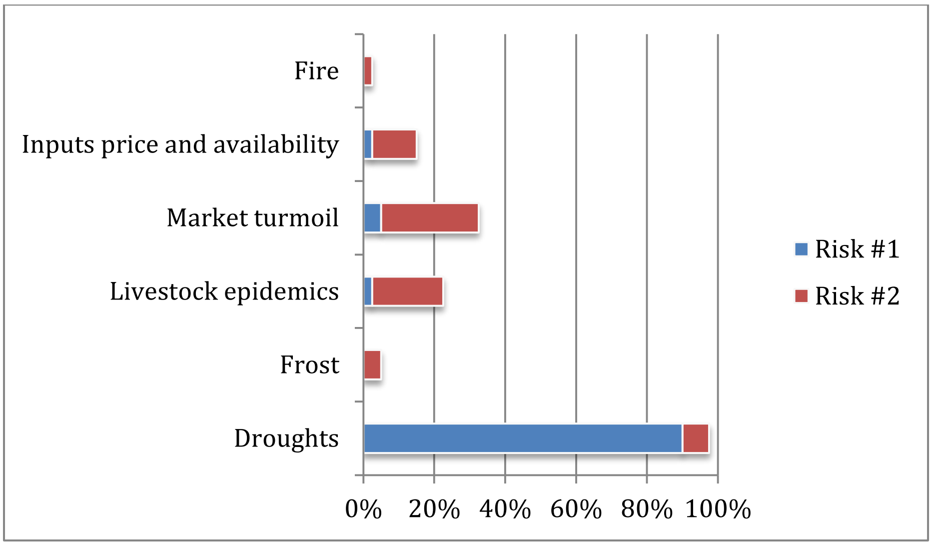

Chart 34 - First and second risk to the farm (% of respondents)

As we couldn't make a clear distinction between the severity and the likelihood of a risk during the survey, we cannot affirm whether farmers' perception are shaped by a representativeness heuristic (Pratt et al., 2008), consisting of underestimating other risks due to the vivid memory of an overarching risk (while formulating the question, all other risks seemed clearly of less importance to most farmers). It is likely, though, that farmers tend to attribute to droughts the paternity of agro-ecological and socio-economic changes that occurred in the last thirty years.

Acceptance of climate change

Farmers of Beni Khirane and Smaala communities recognize a number of climate change symptoms pertaining mainly to drought (Chart 35). The majority of interviews disagree with the idea that "droughts are more and more severe" because they are in general less vulnerable to drought than in the 1980's. Opinions are shared on the frequency of droughts: 50% think that "droughts are more and more frequent". A large majority (92.5%) thinks that the overall amount of annual precipitation is decreasing. Thus, in the farmers' perceptions, climate change translates into the recurrence of extreme dry events, although their impact is less than 30 years ago, thanks to improved adaptive capacity. The other perceived symptom of climate change is the rainfall inter-annual (97.5%) and seasonal (95%) variability. Farmers are particularly worried about periods of drought through the agricultural cycle, whether at the beginning (late rains) or at the end of the cycle (FGD Beni Khirane).

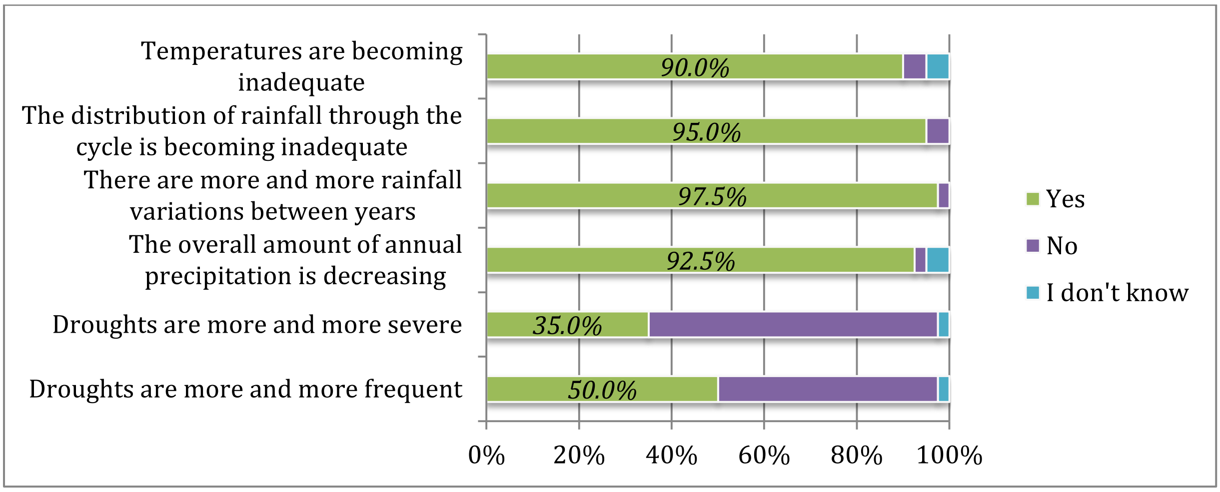

Chart 35 - "Do you agree with the following statements referring to drought?" (% of respondents)

The acceptance of changing climate in the last decades is largely rooted in the population. However, when interviewed on the continuation of this trend in the coming decades, 85% of the farmers leave it to the religious fatality (Chart 36). These farmers invariably answered *Insha'allah* while pointing their finger to the sky. It doesn't mean that they haven't heard of climatic risks of the 21th century; but religious beliefs definitely add additional uncertainty to scientific uncertainties around climate change.

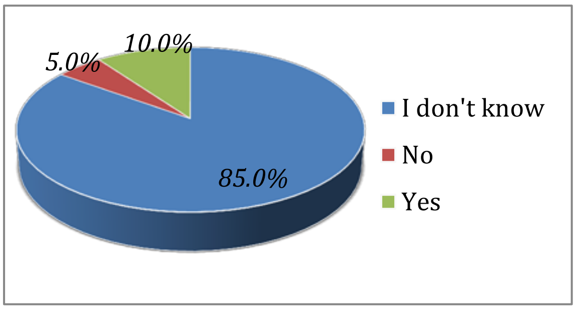

Chart 36 - Drought trend in the next decades (% of respondents)

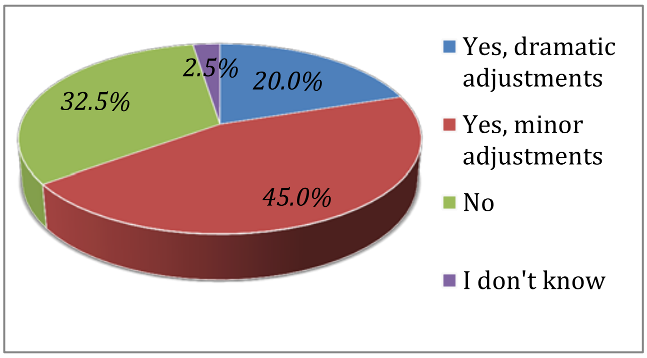

Chart 37 - Need for adaptation of agricultural practices to changing climate (% of respondents)

This vision of climate change determinants seems to have an important influence on the need for adaptation. 32.5% of the respondents think they shouldn't change their practices (Chart 37). 45% agree on the need for minor adjustments in farm management. Only 20% recognize the necessity of dramatic adjustments, such as conservation agriculture for instance. Paradoxically, we heard several time farmers saying "I will change my practices if I can afford". Although not changing might cost way more in the coming decades, innovative practices are not seen as an adaptation to external stimuli that are probably not fully understood, but a luxury for better-off farmers. It raises the double question of awareness of climate change and socio-economic appropriateness of alternatives for smallholders. Furthermore, few farmers referred to the expansion of irrigation as the solution to drought risks, regardless of its technical feasibility. This vision emphasizes the role of water as the key limiting factor, and the direct supply of water (rain or irrigation) as the only variable of adaptation, that would in turn deter any action on management practices.

The attitude towards climate change adaptation is not determined by the farmer's age (no significant correlation). Wealthiest farmers are more susceptible to call for dramatic adjustments in agricultural practices. Farmers characterized by high stocking rate are found in the category in favor of minor adjustments.

Acceptance of land degradation

The long-term erosion of crop yields is commonly attributed to climate change, not to land degradation (El Koudrim, personal communication). In the baseline survey of the CANA project, 12.2% of the farmers indicated that their soils were threatened by erosion (2013). In our survey, 7.5% of the respondents reported erosion problems, recognized through rill formation. This problem was taken quite seriously by these farmers. Land degradation hasn't been tackled by INRA-ICARDA projects in this area.

3.5.2 Time preferences and risk mitigation strategies

Planning horizon

Temporal dimensions of conservation agriculture tend to be underestimated (Titonnell et al., 2015). However, the farmers' relation with time is an important determinant of conservation agriculture adoption (Pannell et al., 2014). Grasping the time horizons of farmers allows understanding how they deal with uncertainties implied by risks and acute inter-annual variability, and to what extent adaptation options match the constraints of their agenda. It is particularly true with residues retention, as positive agronomic effects get bigger over time, whilst some shortcomings must be overcome in the first years (e.g. risk of N immobilization, weeds). For some authors (Tittonell et al., 2015) synergies are possible with different time horizons. For example, soil fertility might increase livestock feed in the longer term, through the increased production in grain and not-retained residues.

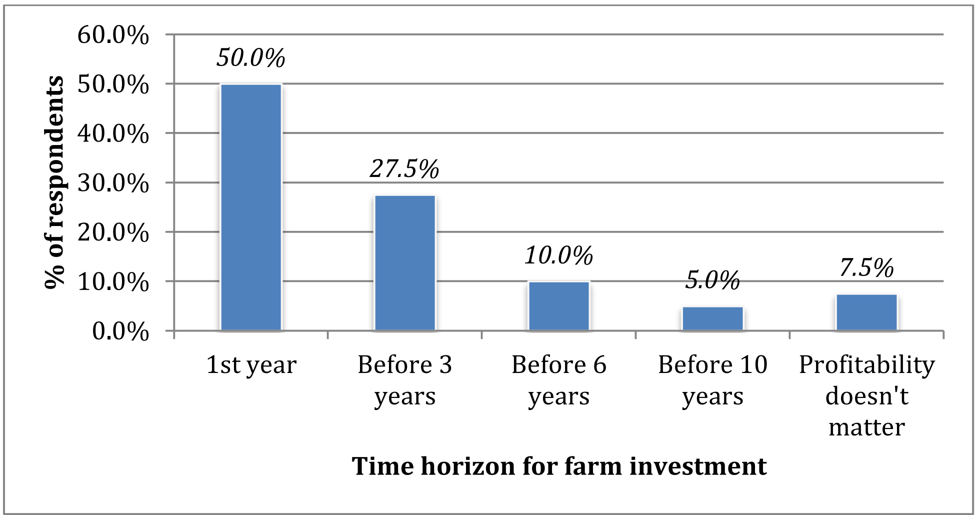

Chart 38 - Time horizon for farm investment or practice change (% of respondents)

We asked the farmers of Smaala and Beni Khirane when they expected a return on investment (material investment or technical change). Half of them expect the investment in the innovation to be paid off after the first year (Chart 38). Another 27.5% are ready to renew the experience during 2 or 3 years before being convinced and continuously adopt the technology. For a wide majority of farmers, this time horizon leaves little room for trial and error. This tight time horizon reflects the structural fragility of household economies and / or a lack of knowledge of the time needed to restore agro-ecological potentialities of soils. It was confirmed by the relatively important rate of trials abandonment after one year in the CANA project.

The FGD participants in Beni Khirane admitted that farm investments are conditioned by the visibility on returns. In this regard, the volatility of market prices prevents major changes in production systems and crops management. There is no significant correlation between time horizon and other variables. However, households who have a time horizon superior to 3 years tend to have more croplands and more livestock (Chart 39).

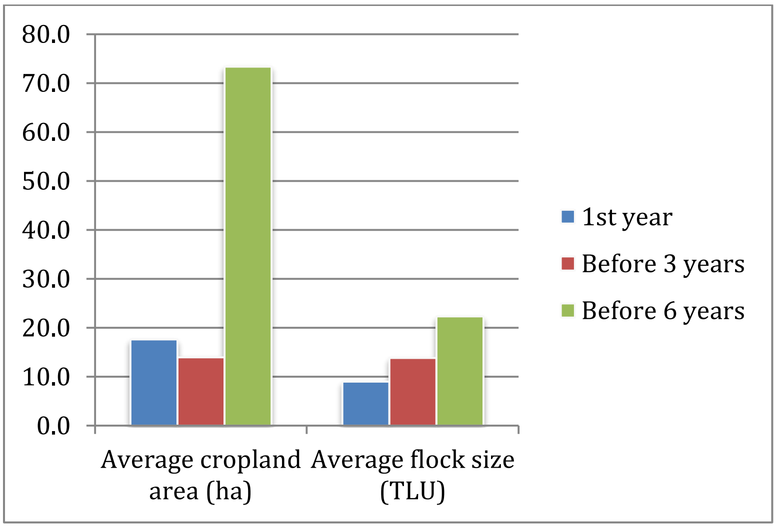

Chart 39 - Time horizon for farm investment and farm characteristics

Flexibility

Flexibility is an important characteristic in production systems affected by uncertain climatic circumstances (Magnan et al., 2011). Flexibility describes the farmer's capacity to adjust inputs and plans during the growing season, including crops abandonment if climatic conditions are uncertain. In semi-arid areas of Morocco, flexibility is an indicator of risk appraisal and capacity / willingness to mitigate the drought impact on household economy.

We asked the interviewees whether they would change their plans and practices in case precipitation starts late or satellite forecast is pessimistic. More than two third of the respondents assert they are not flexible at all in case of late or low precipitation (Chart 40). 27.5% have a limited set of options to mitigate the drought impact.

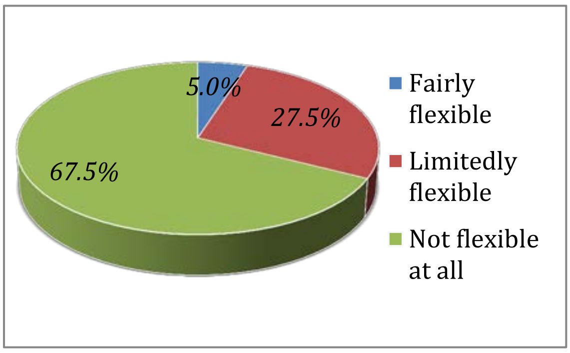

Chart 40 - Flexibility in plans and practices in case of late or low precipitation (% of respondents)

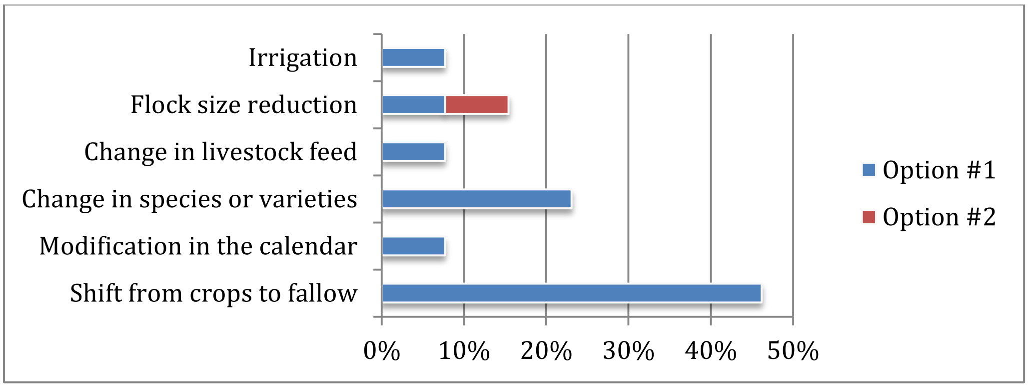

Chart 41 - Possible options reported by the "flexible" farmers (% of respondents, n=13)

The main option if rainfall promises to be late or low consists of shifting from crops to fallow (Chart 41). If the risk of crop failure is high, it is in the interest of farmers to cancel sowing and leave some parcels to weedy fallow, which will in turn benefit soils and productivity the year after. This adjustment seems rational but was quoted by only 15% of the interviewees. Changing crop species or varieties is a possible variable of adjustment: it can be achieved through dry-tolerant species (e.g. barley instead of wheat), short-cycle varieties or late-sowing species (e.g. forage pea instead of cereals). Another option is a change in the livestock population: reducing the flock size or at least fattening less lambs/calves is an alternative to low feed supply. Few farmers mentioned other options such as increased irrigation (when feasible) or changes in livestock feed (more marketable by-products).

We didn't detect significant correlations between flexibility and other variables. One could expect that smallholders are less flexible (e.g. if they are in a 2 or 3 years rotation, and their land was already in fallow the year before). The "flexible" farmers do not particularly grow more weedy fallow or leguminous crops. There is no noteworthy variability between respondents in terms of livestock ownership.

Choice experiment

We proposed two choice experiments to the interviewees. In each experiment, the respondent is being presented two practices. The first practice refers to current farming practices. The second practice refers to an innovation (not explicitly named "residues retention") which involves different benefits, costs, risks and time horizons.

Table 25 - Choice experiment #1

Choice experiment 1	*Practice 1*	*Practice 2*
Highest grain yield	40% of the years	60% of the years
Risk of crop failure in dry year	High	Medium
Residues availability	80%	50%

Table 26 - Choice experiment #2

Choice experiment 2	*Practice 1*	*Practice 2*
Highest grain yield (5 first years)	40% of the years	60% of the years
Highest grain yield (after 5 years)	20% of the years	80% of the years
Residues availability (5 first years)	80%	50%
Residues yield (after 5 years)	5 $t.ha^{-1}$	7 $t.ha^{-1}$

In the first choice experiment (Table 25), the grain yield is higher with the innovative practice in 60% of the years, against 40% with the conservative practice. This practice is more adapted to the drought risk ("medium" risk of crop failure). But fewer residues are available to the farmer (50%, against 80% with the first practice).

In the second choice experiment (Table 26), we added a temporal dimension to the practices effects. With the practice 2, the chances to get a better grain yield rise to 80% after 5 years, and the residues availability is compensated for by a higher residues yield after 5 years (7 $t.ha^{-1}$ against 5 $t.ha^{-1}$ with the current practices).

The respondents took time to formulate an answer and asked for detailed explanations. The results of this exercise are striking (Chart 42).

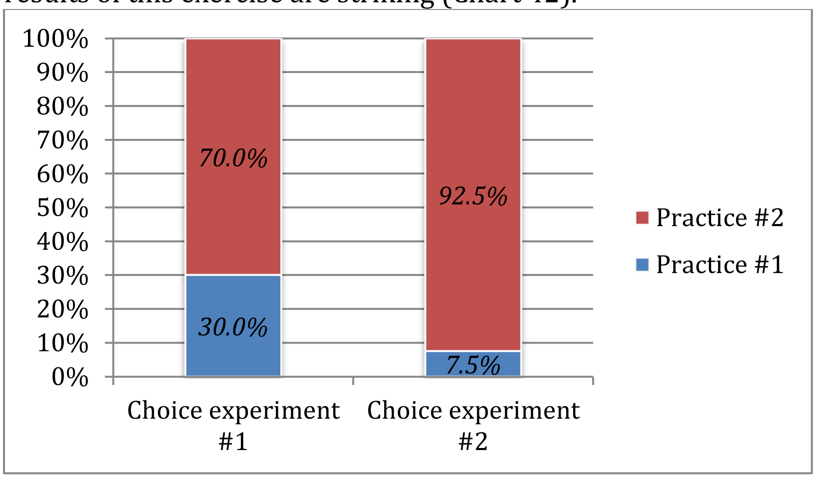

Chart 42 - Choice experiments (% of respondents)

In the first choice experiment, 70% are already seduced by the innovative practice. We know that the properties of this practice meet the decision-making factors (yield) and the risk perceptions (drought). The only disadvantage lies in the less availability of residues, due to retention. The result can be interpreted as follows: 30% of the farmers think that the reduction in residues use for feed is insurmountable, while 70% consider it is justified if the outcomes, albeit uncertain, improve yields and risk perception. For the second choice experiment, the results are straightforward, as the benefits of the innovation get bigger after 5 years while uncertainty decreases and shortcomings (residues availability) are mitigated. As a result, 92.5% of the farmers would go for this innovation.

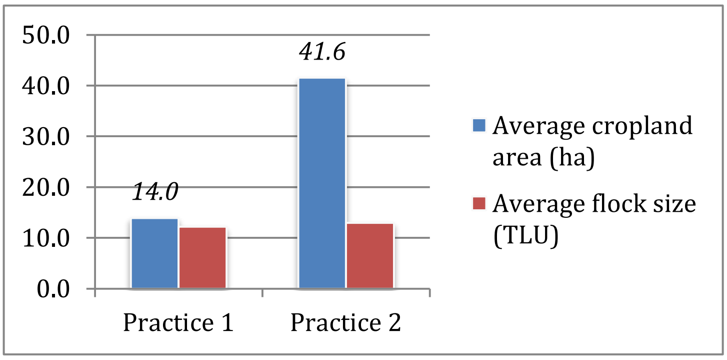

Chart 43 - Choice experiment #1 and farm characteristics

In the first experiment, farmers who chose the innovative practice (# 2) own on average more land (41.6 ha on average) while those who preferred sticking to the current practice (# 1) are small-scale crop farmers (14 ha on average). The livestock characteristics are similar, though (Chart 43).

Risk mitigation

Generally speaking, farmers of Smaala and Beni Khirane have integrated the drought risk in their farming strategies. Since the catastrophic droughts of the 1980's, which led to critical changes, farmers are used to the recurrence of droughts and the temporal variability of precipitation. In consequence, we cannot identify a threshold of risk severity (e.g. critical level of cereal yield in a dry year) that would spur farmers into engaging in short-term adjustments or longer term adaptation.

Low flexibility, associated to limited conscientization about need for adaptation and short-term time horizons, illustrate an endowment effect in risk perception (Patt et al., 2008). Before a recurrent risk, farmers tend to do nothing, giving more worth to what they already possess or obtain thanks to what they do.

Nevertheless, the choice experiment shows that when all elements of a system, meaning possible costs and benefits in specific timeframes, are known, most farmers are possibly interested in changing practices. This result contradicts somehow the short-term planning horizons of most farmers. In this respect, risk perception in Smaala and Beni Khirane is characterized by an omission bias (Patt et al., 2008): farmers seem unwilling to take an action that would potentially have negative consequences (e.g. decrease of residues availability, uncertain yield improvement), even if it eliminates another risk. It is plausible that the uncertainty of benefits and the need to see tangible results before trying remain determining factors of decision.

Finally, the principal attitude to drought risks isn't that of a pro-active search for adaptive options but consists of a hoarding strategy to prepare bad years. After a good harvest, straw and grain are stockpiled (as written before, 60% of the farmers store straw during more than one year), and used either for animals or for trade when the need for cash or feed is critical. It seems that this strategy, also supported by the diversification of feed and governmental programs, is sufficient, so far, and doesn't require more flexibility and adaptation.

Conclusion of the fifth result

Water is considered the major limiting factor, overshadowing soil health and land degradation. The temporal variability of rainfall is the most commonly admitted climate change symptom. Although this risk is recognized, it doesn't translate into seasonal flexibility or longer-term thinking. Drought risk is rather mitigated through hoarding strategies. Farmers plan in terms of short-term horizons, which overall seems to reflect the under-estimation of the need for structural adaptation and of the time needed for this. Yet, choice experiments have paradoxically shown a clear interest in an alternative whose benefits are not immediate, not guaranteed and suppose concessions (feed availability). It suggests that there is a window of opportunity for a different management of residues, provided the temporal depth of climate change is better assimilated by farmers.

4. Discussion

4.1 Unravelling tradeoffs around crop residues use

In this part, we step back from the presentation of the research outcomes in order to revert to the main research question: "*In the context of rain-fed areas of Chaouia-Ouardigha (Morocco), how do tradeoffs around biomass use influence the adoption of crop residues retention as a soil conservation measure?".* We assemble the diverse dimensions of crop residues use (historical, biophysical, economic, risks) and we characterize the tradeoffs found in the two researched communities.

4.1.1 Characterizing the tradeoff

In Smaala and Beni Khirane, we found a pronounced tradeoff around residues use. The importance of livestock in the production system and the importance of residues for livestock are a major barrier to any other use of residues. We are in a situation of severe competition between feed and, possibly, soil cover.

In our case, the tradeoff is conceptual, so far. There is limited understanding of a tradeoff from a farmer point of view. Residues retention is not practiced consciously and hasn't been promoted as a best practice yet. The benefits of keeping a biomass cover on the surface are recognized by the majority of farmers, but leaving more residues than usual isn't done on purpose, and in most cases, results from the coincidence of residues yield and livestock needs. The empiric acknowledgement of retention advantages is overshadowed by the importance of straw and stubble in the feeding calendar and the lack of confidence in feed alternatives.

Titonnell et al. (2015) describe three regimes of tradeoff: competition, substitutability and complementarities. Even though this study is not aimed to quantitatively define the regime relevant to the area, the findings suggest that the trial or continuous adoption of residues retention, if proposed to farmers in a near future, will clearly touch on competition with feed. A regime of substitutability, where the utility as feed and the utility as soil cover are inversely proportional, is not reached because of the importance of residues for feed and the uncertain benefits of retention in the short run. The adoption of forage alternatives, which have shown promising results, could increase substitutability, but its effects are inherent in the farm size and the relative importance of residues for livestock. A high level of residues retention could in the long term drive the tradeoff to a regime of complementarity, where the benefits to soil positively influence the utility of residues as feed.

The central role of residues in the livestock system is the main factor of tradeoff severity. However, this assertion can be mitigated by two elements. First, the direct economic value of straw and stubble is less significant than their indirect value, through the contribution to livestock production. Stubble is mainly perceived as a "free" resource while straw is only traded by large-scale farmers. The function of stubble and straw remains that of livestock feeding, throughout the year: in normal conditions, all livestock owners will graze their flock in stubble between harvest and sowing, and will use straw as the main forage component of rations the rest of the year. But, and this is the second element, residues are not the sole source of feeding (e.g. straw accounts for 57% of the forage needed). Feed diversification has been a key adaptation measure since the 1990's. Other forms of biomass exploitation for livestock do exist, such as the traditional weedy fallow and the (re-)emerging forage crops. By-products are widely bought as well, showing that farmers have assimilated the point of spending money in feed to increase livestock performances. Investing in livestock production through residues remains highly attractive though, because of the easy access and the perceived low cost of residues (the costs are not decoupled between grain and biomass).

The severity and the parameters of the tradeoff are temporally variable, due to variations between supply, demand and ecological services (Erenstein, 2015). In this respect, the drought risk is a key determinant of tradeoff. The economic and feed value of residues is considerably increased in a dry year. One could still argue that this increased value is limited by the scarcity of this resource. Indeed, droughts spur farmers into fully exploiting, if not overexploiting, the few biomass produced. This strategy is combined with hoarding from better-off years. In the end, the tradeoff should probably be appraised on multi-years cycles. In this context, the possibility of retaining more residues changes the tradeoff paradigm: the appropriateness of the measure is questionable if the biomass yield has suffered from drought, but it also is an alternative to reduce the strain on biomass in dry years. In the end, there is an apparent paradox around residues retention. Retaining more residues on the soil is an agronomic option to adapt the system to droughts, but, meanwhile, the value of residues (economic and feed) has been dramatically increased since the catastrophic droughts of the 1980's. In consequence, the tradeoff is particularly acute in dry years.

4.1.2 Multi-scale tradeoffs

At farm scale, cereal residues compete for two objectives, feed and soil cover. This research demonstrated that forage alternatives could change the paradigm whilst more complementarities could be enabled in the long term by residues retention. In addition, the farmers' attitude to forage alternatives and the benefits of soil cover is generally positive. We can expect that the severity of the tradeoff could be alleviated after several years of partial residues retention for a significant number of farmers.

On the other hand, this study revealed more complex interactions around residues at neighborhood or village scale. Other studies have already pointed out more severe residues tradeoffs at village scale, in Sahelian agro-pastoral systems for example (Andrieu et al., 2015). The present study concurs with this analysis. Unregulated use of stubble has been fueled by different factors: tradition of free grazing inherent in pastoral societies, mistrust between farmers and herders, heterogeneity of land size and household wealth within villages, confused land tenure statuses, weak community conflict resolution mechanisms. Demographic growth and resources rarefaction caused by droughts have exacerbated tensions between farmers. This is particularly true in Beni Khirane community, where inequalities are most striking. In that sense, the residues tradeoff at village scale resembles a social tradeoff, an aspect identified by other researchers, in Mexico for instance (Beuchelt et al., 2015).

The adoption of residues retention at household level requires certainly awareness-raising, capacity building and thorough costs-benefits analysis. But social tradeoffs at village scale would add more complexity to the adoption process. Livestock-oriented smallholders and landlords are interrelated in different ways: stubble grazing (rented, agreed or unauthorized), straw and grain trade, labour. In these circumstances, field protection against unauthorized grazing is a thorny matter. The adoption of residues retention by middle- and large-scale farmers might have a negative impact on poor farmers. Any ban on free stubble grazing is susceptible to badly affect this category of households. Moreover, it could contribute to increasing the shadow value of stubble (Magnan, 2015), making more difficult the transition of smallholders to conservation agriculture. Magnan concludes that farmers are interdependent in their decision to adopt residues retention or not (2015). This has to be taken into consideration before any attempt to disseminate this technology.

4.1.3 Tradeoff determinants

The crops-livestock relation and the tradeoffs around residues are determined across socio-ecological contexts by their agro-ecological potential, market opportunities, land availability and farming systems (Tittonell et al., 2015).

Our study integrated a number of explanatory variables determining crop residues tradeoffs. The Factor Analysis enabled the identification of seven factors which together explain 67.7% of the total variance in the sample (Table 27). The first factor, re-named "resources endowment", includes variables describing the household's wealth in terms of land availability and livestock, and accounts for 17.9% of the explained variance. It confirms the importance of the cultivated area and flock size, the two core components of the integrated crops-livestock system. Other factors emerged from the factor analysis: residues management, crops-livestock relation (stocking rate), communal grazing (narrowly linked to the community), feed, crop productivity and importance of crop residues to household incomes.

Table 27 - Factors and variables with high loadings

Factors	1	2	3	4	5	6	7
Variable	Resources endowment	Residues management	Crops-livestock relation	Communal grazing	Feed	Crop productivity	Importance of CR to incomes
Flock size	.766						
Cultivated area	.747						
Crop residues net incomes (normal year)	.692						
Land rights	.666						
Involvement in the CANA project	.657						
Stubble left on soil (normal year)		.684					
Stocking rate			.613				
Community				.537			
Unconsented grazing				-.539			
Feed expenditure (normal year)					.505		
Barley straw yield (normal year)						-.605	
CR contribution to cereal incomes (normal year)							.810
Explained variance (%)	***17.9***	***10.9***	***9.2***	***8.2***	***7.8***	***7.6***	***5.8***

Other variables, not directly tackled in this research, should be taken into consideration: labour; farming system intensity; and soil & land status.

The availability of qualified and cheap labour appeared along this study as a limiting factor in practices determining crop residues use. The lack of shepherds or family workforce jeopardizes the retention of residues while forage crops, feed alternative to residues, are so far too labour-intensive to be widely adopted. The cost of daily workers considerably reduces the margins of farmers: this is also observed at straw bales packing stage. Beyond, the farmers' propensity to change behaviors seems constrained by a longstanding dependence in a mechanized system, which was a factor of rural-urban migrations few decades ago.

The system intensity determines the severity of tradeoffs. The intensification can relieve pressure on crop residues and minimize tradeoffs (Valbuena et al., 2015). The importance of crop residues for feed is narrowly related to the farming intensity (Figure 12), farming intensity being defined by the number of cropping seasons per year, population density, and market connectivity (Titonnell et al., 2015). As regards our study, we don't have satisfactory proxy indicators to describe farming intensity. The ratio leguminous crops – fallow / cereals, which doesn't embrace multi-year rotations, never appeared as a significant explanatory variable.

Finally, soil features and land degradation should be included in further studies of tradeoffs for residues use. Factors such as soil fertility, soil depth and slope proved to be noteworthy tradeoff determinants in other studies (Jaleta et al., 2013). This study showed that farmers adjust residues management to the parcel characteristics (remoteness, type of soil), while yields are spatially variable as well. The spatial variability of soil cover effects is likely to reinforce the importance of soil characteristics in tradeoff analysis.

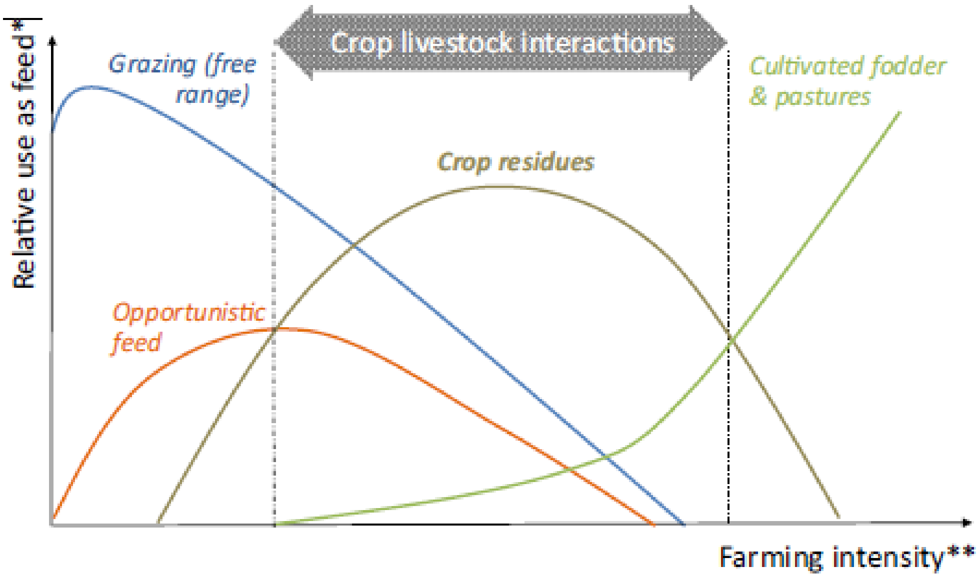

Figure 12 - Hypothesized relationships between farming intensity or and the importance of crop residue biomass as a source of feed (Tittonell et al., 2015, adapted from Paul et al., 2013)

4.1.4 Farmers' heterogeneity

Tradeoffs are "context-specific" due to numerous associated factors and their inter-linkages (Erenstein, 2015). The acuteness of residues tradeoffs at village scale is closely related to the heterogeneity of farmers, particularly within Beni Khirane community. In this community, problems of unconsented grazing and practices aiming to limit opportunities for neighbors (e.g. stubble ploughing) reflect conflicting interests and the relative weakness of collective ties. Households have various assets, profiles, livelihoods and priorities. The heterogeneity of farmers and their complementarities are inter-related (e.g. small livestock owners work as daily workers for landlords). These complementarities are expressed through monetary relationships which somehow contradict the free use and common management of resources inherited from the pastoralist tradition.

Following an empiric method, we can outline a basic typology of farmers based on the two main criteria – arable land availability and livestock size (based on the regression between these two variables). Five major groups can be identified, with variable importance of residues and variously acute tradeoffs around residues use (Table 28). On top of this, social tradeoffs at village scale should be considered, so as to distinguish Smaala and Beni Khirane communities.

Table 28 – Typology of farmers based on empiric characterization of residues importance and tradeoff severity

Group	Importance of residues	Tradeoff
Crops-oriented smallholders	No or few needs of residues for feed	Moderate
Livestock-oriented smallholders	Critical importance of residues for feed	Very severe
Middle-scale farmers (crops and livestock)	High importance of residues for feed, little room for feed alternatives, few incomes from straw	Severe
Crops-oriented middle-scale farmers	Moderate importance of residues for feed, few incomes from straw	Moderate
Landlords (crops and livestock)	Important incomes from residues, high importance of residues for feed, room for feed alternatives	Severe

4.2 Towards action

4.2.1 Methodological challenges

Additional substantiated research is needed to bridge the knowledge gap on crop residues retention, before any attempt to introducing farmers to this technology. Some methodological flaws or grey areas, in our research and in other studies, deserve to be ascertained and addressed by researchers.

Data limitations

This study suffered from the distortion between the limited sample size and the high number of variables. The sampling problem was partially circumvented through a qualitative quota sampling method which helped grasp the diversity of households, which indeed proved to be a crucial determinant of tradeoffs around crop residues. On the other hand, it was difficult to statistically extrapolate groups' behaviors that would be illustrated by homogeneous trends in clusters of variables. Identifying proxy indicators relevant to residues tradeoff is a prerequisite. This result was partially achieved thanks to factors analysis. However, one can wonder whether a limited number of variables are susceptible to embrace the subtleties of an integrated crop-livestock system and the role of residues in this system. The imperfect result of the Hierarchical Agglomerative Clustering confirmed it.

Additionally, we observed some inconsistencies between certain variables. Residues needs and expenses didn't always match actual production. For example, several farmers reported a straw production which was finally higher than the biomass availability on their parcels, if standard harvest indexes were applied. It reflects evident limits in data collection. We can attribute these limits to translation, interview conditions, and difficulties for the interviewees to look backwards and give accurate figures. Quantifying stubble and straw is particularly sensitive. Onsite measurements or sampling of residues could be worthwhile to back information given by farmers, if timely done. Other methods inspired from participatory rural appraisals (e.g. drawings, representation of quantities) could also help reach a finer analysis.

Defining crop residues retention

The retention of crop residues retention can be defined through multiple parameters. The lack of standard definition of retention is an obstacle to analysis. Some researchers remain vague on the exact treatment applied to residues in field experiments. In the end, what does "30% retention" mean?

The inclusion of straw in residues to be retained is not always clearly stated (Mohammad et al., 2012). Some experiments are made with the retention of loose straw (Mrabet, 2011), some others not. When straw is removed, the height of straw cut may vary a lot (between 10 cm and more than 30 cm), with a substantiated effect on biomass cover. The ratio between flat mulch and standing stubble has a significant influence as well (Sommer et al., 2012). The mulch thickness and the percentage of soil cover by residues are other important parameters, variably considered by existing researches. Using the control of grazing to measure residues retention changes the paradigm. The number of days of stubble grazing, the stocking rate and the spatial variability of grazing then become variables of significance (El Koudrim, 2015).

Often, as different aspects are combined (e.g. straw cut and retention of loose materials, Sommer et al., 2012), attributing a change in agronomic performances to a specific parameter becomes difficult and uncertain.

The variability in the design of residue treatments makes comparisons harder. It should encourage researchers to undertake long-term trials with multiple parameters (separated and combined) pertaining to residues retention. Ultimately, it seems that the percentage of retention matters less than what is exactly left on the surface, and how (flat or standing, loose residues or not, height of cut, percentage of cover, thickness). The treatments offering the most promising results and reducing the tradeoff for residues use could then be tried by farmers. In the case of

Morocco, the combination of straw baling with a medium height of cut (~ 20 cm) and a limited period of stubble grazing (~ 1 week) might both maintain, to some extent, the feed function of straw and ensure a more effective soil cover.

Furthermore, researcher-controlled trials are controversial since they rarely integrate the actual conditions encountered by farmers. Controlling animal grazing, from own flock or other flocks, is particularly challenging to farmers. Targeting specific forms of residues retention is not an easy task to implement either. In addition, the advantage of experiments with partial or total retention compared to plots with complete removal is questionable, since, except for the 40% of farmers practicing summer ploughing, a proportion of residues actually remain before sowing, at least in normal and good years. In other words, the 0% retention is not always a representative baseline trials with retention could be compared to.

Evaluating retention benefits

The interest of residues retention could be fully appraised through a multi-year costs-benefits analysis that would include multiple parameters, i.e. rainfall variability, yield variations, farmers' choices in terms of land use (rotations) and flock size. Moreover, farmers' decisions regarding straw use (timing for trade, stockpiling) should be integrated in such an analysis.

In addition, some long-term effects of residues retention stress the need for an analysis in the long run (10 years or more) integrating temporal variability of factors, such as the progressive increase in soil indicators and yields (grain and biomass), the gradual decrease in fertilizers & herbicides needs, as well as the indirect effects of feed changes on livestock profitability, thanks to enhanced animal health. On the other hand, the possibility that the stubble shadow value increases with privatization of residues use by a part of the farmers should be taken into account.

4.2.2 Recommendations to practitioners

Conservation agriculture without soil cover?

The question of proposing a conservation agriculture package without crop residues retention is being debated, in Morocco and in international arenas. Given the importance of residues for feed in certain farming systems, one can wonder if the slight yield improvement recorded with residues retention, in comparison with no-till system without retention, justifies the dissemination of this technology.

This is a position defended by a number of researchers from INRA-Morocco, for whom the main problem remains the perturbation of soils by tillage. The CANA project demonstrated that no-till could potentially improve grain and biomass yields. Although the yields under conventional tillage were still better in the first year of implementation, no-till yields prevailed in the second and third years. In the second year, a dry year, the yields of no-till trials exceeded that of conventional tillage by 22% (Boughlala, 2015b). Similarly, a long-term experiment conducted in Chaouia emphasized an average increase by 10% in no tillage with residues removal compared to conventional tillage (Mrabet, 2011). This improvement is significant *per se*. It is not obtained at the price of an acute tradeoff, but, on the contrary, with decreased production costs (Boughlala, 2015b). The socio-economic cost of an additional yield increase of 5%, thanks to soil cover (Mrabet, 2011), is more problematic, unless the equilibrium of the livestock-crops system is modified, through a livestock system intensification for instance (which requires more energy-dense feed).

Opinions on an adequate percentage of retention, albeit hard to determine and control, as explained before, are more unanimous. The retention of all the residues adds little value to the retention of 50% or less (Mrabet, 2011), but its cost to the farmer is much higher. In the end, the percentage of retention should above all balance both the benefits and the farmers' capacity or needs (feed). A threshold and a ceiling of retention, adjusted to the local circumstances, should be determined accordingly.

Other researchers question the effectiveness of the conservation agriculture package as a whole or with room for removing some components i.e. crop residues retention. Giller et al. (2009) remind of the fact that conservation agriculture was conceived as a holistic package that could only work out if the different components are applied simultaneously. These authors emphasize that the constraints to adopt the package as a whole "makes it imperative that the benefit of each principle is properly evaluated", which had been limitedly done until recently.

In theory, "almost all advantages of the no till system come from the permanent cover of the soil and only a few from not tilling the soil" (Mrabet et al., 2012; after Ortiz et al). Implementing no tillage without soil cover is susceptible to increase vulnerability to erosion, though. Experiments in Morocco showed that runoff caused by a high-intensity rainfall event (60 $mm.h^{-1}$) is higher in a no till system without residues than in a conventional system, while it remains low when no till is combined with residues retention (Moussadek et al., 2011). Different studies came to the conclusion that retaining residues in conventional tillage helped increase the yield compared to no-till with bare soil (Verhulst et al., 2011; Mohammad et al., 2012): in these cases, benefits seemingly come from soil cover rather than no tillage. Nevertheless, no-till can achieve some of the desired effects of residues retention i.e. water efficiency, soil structure, SOM (Giller et al., 2009). The stability of aggregates is in many circumstances attributed to no tillage rather than soil cover.

The identification of the main limiting factors at local scale is a prerequisite in the decision to combine no till and residues retention, or to apply only one component. In Oued Zem region, the relatively low erosion rates in flat areas may indeed be adapted to no till without residues retention. The risk of no-till seeder clogging by residues is another bottleneck of the association of these two practices.

As regards the relation between rotation and residues retention, the complementarity of the two practices is clearly proven, since rotation addresses the weeds problem aggravated by residues. Besides, the integration of leguminous crops in the rotation is particularly consistent with the necessity to develop forage alternatives in the residues retention system.

In conclusion, the acute tradeoff for residues use encountered in Moroccan drylands seems to speak in favor of a "step-wise adoption" (Pannell et al., 2014). Using no-till as an entry gate to conservation agriculture has already demonstrated promising results, that have to be confirmed over time. The retention of residues can constitute a second step, once this technology is tailored to the local peculiarities and needs. It is likely that retaining residues wouldn't be beneficial to all farmers. Therefore, flexibility definitely is a success factor of conservation agriculture adoption. But ruling out a better management of residues would resemble a missed opportunity and could invalidate the benefits of no-till in the long-term

Approaches to residues retention introduction

Step-wise adoption of conservation agriculture suggests the identification of decisive entry points to introduce residues retention. This study revealed the heterogeneity of farmers and success factors of this practice. In this respect, a number of recommendations can be derived.

Targeting the appropriate audience is a key step. Focusing first on farmers who encounter a moderate tradeoff as of now is likely to lay solid foundations for wider adoption. The early adopters directly targeted by a residues management project should meet most of the following criteria:

- Crops-oriented small- to middle-scale farmers. Farmers with no or few livestock and farmers who don't trade important volumes of straw should be targeted in priority. The few farmers who own no livestock could more easily experiment residues retention.
- Proven intrinsic motivation in no till (adoption of no-till on partial or total area of the farm, without incentives)
- Adoption of good practices regarding rotation; existence of feed alternatives (forage crops and / or weedy fallow)
- Positive attitude to forage alternatives and residues retention

Large-scale farmers could be interested in changing residues management, provided their incomes from straw sales are not too badly affected. So far, conservation agriculture has been adopted worldwide by better-off farmers mainly. The CANA project didn't depart from this tendency: most participants to the no-till trials were landlords. Disseminating conservation agriculture to larger fringes of farmers is a challenge. Any project of residues management should ensure the adjustment of the technology to average farmers' characteristics. It is also a matter of staying aligned with the Green Morocco Plan objectives (Badraoui et al., 2010). Establishing a pathway to adoption tailored to different categories of farmers is important.

The process established under the CANA project, which consists of relying on progressive farmers grouped in an association meant to scale out the technology seems relevant to crop residues retention as well. The no-till farmers association, Al Baraka, could fulfil this role.

Addressing the socio-economic tradeoff at village scale is crucial to the success of residues retention adoption by a growing number of farmers. It means that the supposedly late adopters, the livestock-oriented smallholders who face an acute tradeoff around residues, should be included in any project from the beginning. For these, the sustainable intensification of the livestock production, through better feed (e.g. forage crops), valorization of livestock products and reproduction control, is leverage to alleviating risks related to free grazing and inequalities. In this regard, starting with a pilot approach in Smaala community, more homogeneous and less prone to free grazing, could be relevant. Best practices could be then replicated and adjusted to the specific context of Beni Khirane community.

Investing in awareness-raising about conservation agriculture, feed alternatives, land degradation and adaptation to climate change probably is essential to drive farmer decisions towards more sustainable practices. Helping farmers establish causalities between factors and symptoms of productivity decline is likely to arouse behavior change. Parallel to this, fostering better community-based management of resources, including residues, is a necessary step to mitigate village-scale tradeoffs. In addition, strengthening the farmers' capacity to plan their annual feed needs is another tool to prepare the ground for better residues management. It could include spatial patterns of stubble grazing in alternating plots at farm level.

Practically, onsite trials involving residues retention should be first established where conditions would make the benefits of this practice conspicuous. Priority could be given to rain-fed lands located on marginal slopes, vulnerable to erosion, where economic stakes are lower compared to flat croplands. Trials with moderate objectives could be put in place in these lands. Various treatments could be experimented in the first years: no summer stubble ploughing, medium height of straw cut, no straw retention, limitation of the duration of stubble grazing to one or two weeks, residues trashlines along contours (land management practice experimented in Uganda). More ambitious treatments (less straw baling, higher height of straw cut, and / or ban on stubble grazing) could be tried later on plots where the first treatments were successful.

To minimize the tradeoff, residues retention could be adjusted to residues productivity: no retention after a drought; limited retention after a normal harvest and larger retention after a good year. Farmers already adapt residues management to annual rainfall variability.

Finally, introducing farmers to residues retention should be embedded in a strategy aiming at reviewing the crop-livestock integration. As concluded by most researches on crop residues tradeoffs, crop-livestock patterns should be shaped by an objective of sustainable intensification, totally aligned with the Green Morocco Plan. In this respect, conservation agriculture interventions are to be consistent with other actions focusing on natural resources preservation and value chains integration, whether for high-value crops or market-oriented livestock production.

5. Conclusion

This research acknowledged the severe tradeoff between competing objectives around cereal residues use in semi-arid areas of Morocco. The importance of livestock in the production system and the importance of residues for livestock are a major barrier to any other use of residues. Straw trade, albeit secondary, also contributes to the tradeoff. These uses are a major hindrance to the uptake of residues for soil conservation. In other words, farmers give priority to "feeding the cow" rather than "feeding the soil". The retention of residues for soil cover is not practiced on purpose by farmers. Therefore, the tradeoff is only conceptual, until now, but characterizing it helps prefigure the challenge that any intervention aiming to introduction this technology to farmers would face. The tradeoff plays out at farm level, but also at village scale. This latter is fueled by the heterogeneity of farmers' situations, which translates into inequalities of access to land and free grazing disputes. Acknowledging the socio-economic diversity of farmers underlines how context-specific tradeoffs around residues use are.

Residues retention shouldn't be looked at separately but integrated in a wider approach aiming towards sustainable intensification, and looking at both the supply and demand sides of feed and biomass. Targeting primarily farmers who would face moderate tradeoffs (crops-oriented small- to middle-scale farmers, mainly in Smaala community), is a relevant entry gate, but a holistic approach including all categories of farmers in a step-by-step process is the best alternative to overcome crucial grazing issues caused by economic and land inequalities.

This study confirmed the necessity of a systemic and cross-disciplinary understanding of residues tradeoffs, across different angles embracing the farming system (biophysical, economic, socio-cultural, risks). Still, linkages between practices, performances, behaviors and perceptions must be identified accurately. This couldn't be fully achieved due to the limited sample size and some flaws in the interviews, whilst the set of variables primarily defined was complex. Moreover, the analysis of perceptions suffered from the lack of experience of farmers with innovative practices: speculating around a practice – soil cover with residues – which is not consciously experienced is a limitation of this work, at this stage of farmers' introduction to conservation agriculture.

To further assess the adoption potential of crop residues retention, the lens could be placed on the following aspects:

- Longer-term crop retention trials, in real conditions (which implies grazing risks), with standardized parameters, in order to then refine and tailor the technology
- A broader understanding of the straw market, at local, regional and national scales. A fine insight on policies, fluxes, economics and seasonality would clarify the importance of straw trade in the residues tradeoffs.
- Context-specific data about erosion are needed.
- A costs-benefits analysis (CBA) integrating variations in the future (e.g. discount factor, soil fertility variations), along with a crop yields model (e.g. APSIM). This analysis should address the problems of uncertainty in yield benefit (more experiments needed) and multiplicity of parameters (enabling conditions, feed alternatives, farmer's willingness to compensate for residues retention ecological shortcomings) and outcomes (soil health, effects of new feed regimes on livestock productivity). The CBA could be declined for different profiles of households.
- Developing optimization or simulation tradeoff models
- CBA and tradeoff models could be coupled with Multi-Criteria Analysis as a tool to support discussion with communities.

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Annex I – Focus Group Discussion template, Timeline

FOCUS GROUP DISCUSSION
Timeline

Objectives
To introduce the study and the following surveys
To grasp and visualize trends and changes in climatic patterns, land use and agricultural practices in the last decades
To stimulate discussion on how and why practices changed

Participants
2 to 4 villagers
Preferably elders; not necessarily the same participants as for the FGD on crop residues

Material needed
Flip chart, marker pen (different colours), post-its
Use an A0 map of the area to visualize locations the participants refer to

Organization
Step 1 - Presentations, introduction of the study and the purpose of this participatory exercise
Step 2 – Reconstruct a chronogram on the flip chart (on the floor), starting from the 1950's (independence, time of elders' youth). Invite participants to indicate milestones or reference dates (e.g. 1956, end of French protectorate; 1999, Mohammad VI anointed; 2008, launching of Green Morocco Plan; important elections, international events, national plans, climatic disasters etc.)
Step 3 - Invite participants to think of a key moment relevant to the topics listed below (changes or steps). Write it down on a card (different colors) and place the card on the chronogram.
Step 4 - Trigger discussion to identify reasons behind trends and linkages between trends (especially how the situation of today is a result of lessons learnt from the past)
Step 5 - Review the result by looking for trends or patterns

Guiding questions

Topics
Severity and frequency of droughts (farmers' definition of drought; distinguish "drought", "normal" and "good" years)
Land use changes (croplands, pastoralism, natural vegetation / forest)
Land rights and grazing evolution (from local farmers and external pastoralists, history of disputes)
Crops management: species, tillage (draught animals, machinery, no or minimum till)
Crop residues use (rough proportions: feed, soil cover or other; distinction straw / stubble; removal techniques)
Livestock feeding : type (grazing vs stall feeding, forage, by-products) and calendar
Cereals grain and residues yields (rough estimate)
Farmers' organization
Demographic / migration trends

Annex II – Focus Group Discussion template, Crop residues use

FOCUS GROUP DISCUSSION
CROP RESIDUES USE
Template

Objectives
To get a general picture of what land use practices are, how crop residues are used and what the rationale behind choices is
To understand mechanisms and practices inherent in the community
To introduce the purpose of this study and the upcoming household survey
To help fine-tune the household survey questionnaire

Participants
6 to 10 farmers
Selection criteria: CA association members (2-3), spontaneous adopters of no-till (1), project participant who dropped (1), conventional farmers (1-2), herders (2-3), woman (1?)

Organization
90 to 120 min
Flexibility in questions order and formulation, depending on answers
Allow everyone to speak up
Quantitative figures should be reported on a flipchart, with a comparison between the 3 types of year (yields, residues value, grazing)

Materials
Room with chairs or sofas
Flip chart & markers
Use an A0 map of the area to visualize locations the participants refer to
Meal to be offered

Questions

Questions	***Remarks***
1. Crop residues (CR) uses	
1.1 In this community, how is straw used after harvesting?	Expected answers: straw baling for feed or trade, shed / poultry bedding, soil cover, other
1.2 How is stubble used after harvesting?	Expected answers: stubble grazing, soil cover, burning for soil amendment, other
1.3 How is this quantity of CR determined or controlled by the farmer?	Control on duration of grazing or area grazed or quantity of CR taken/left, rotavator use
1.4 Are there many differences between the farmers in the village in terms of CR use?	Variability between smallholders and large farmers, farmers and herders
1.5 What determines mainly the choice of farmers to use straw and stubble?	Expected answers: herd size, alternative feed, land issues, labour, cash needs, soil characteristics, markets
1.6 Does the importance of CR determine the choice of varieties, seeding rates and rotations?	Barley vs wheat
1.7 What is the economic value of straw and	Straw market price, buyers (poultry etc.)

stubble, in a good, a normal and a dry year?	Renting price for stubble grazing
2. Land and grazing rights	
2.1 Is the access to land equitable for all?	Disparities between farmers and livestock owners
2.2 Are their different statuses in the village?	Statuses: private, individualized collective lands, royal domains
2.3 Are land rights a barrier to investment in agriculture?	Duality between Islamic vs modern legislation (which one is more applied?)
2.4 What are the rules regarding grazing in the community? How / when were these rules established?	Free grazing in croplands. Important aspects: private vs communal lands; farmers vs herders
2.5 Are these rules approved and complied with by the farmers and shepherds?	Smallholders / shepherds more reliant on free grazing so more constrained by CR retention
2.6 What happens if a farmer doesn't abide by the (tacit) rules or is victim of rules violation?	Trust between farmers; legal actions
2.7 What happens if a farmer decides to enforce property rights against common grazing, so as to use CR for soil cover? Can he fence his plots?	Impact on stubble availability & implicit value, and grazing patterns, in the village Fencing cost and feasibility
2.8 What is the effect of uncontrolled free grazing on crops management?	Rapid harvest, reluctance to invest
2.9 Are there agreements / transactions between some farmers and shepherds for grazing?	CR or fallow grazing Now and in the past
3. Livestock feeding	
3.1 What are the sources of feed for livestock owners in the village, in good, normal and dry years?	Per type of livestock. Grazing: number of days and flock size Expected answers: pastures grazing, stubble grazing, straw, green fodder, grain, bushes, by-products, other crops residues
3.2 How important are CR for feeding livestock?	Quantity + quality
3.3 Are you interested in feed alternatives such as those introduced by INRA (forage mixtures, fodder cereals) or by-products?	Potential shortcomings By-products cost and availability (feedblocks, beet pulp etc.)
3.4 If the profitability of rain-fed crops is increased thanks to CA, would farmers intensify or decrease their livestock production?	Change in flock size
4. Conservation agriculture	
4.1 What is the proportion of farmers in the village who apply minimum tillage?	Project direct beneficiaries + other farmers
4.2 Did some farmers try it but come back to traditional systems?	Collect names and contacts, for household survey
4.3 What do you perceive as benefits of retaining the CR (e.g. soil, yields, erosion, labour etc.)?	Agronomic benefits, opportunity costs savings
4.4 What are the drawbacks of retaining the CR, for soils and yields? Are there alternatives to these problems?	Expected answers: weeds, animal manure supply, would encourage free grazing
4.5 What level of yield, supposedly achieved thanks to NT and CR retention, would make this measure acceptable by farmers?	Values in kg/ha (compared to current yields)
4.6 If benefits of CR retention are proven, would some farmers be ready to test it on a plot? On what proportion of the farm area?	Kind of farmers more susceptible to adopt (small-scale vs large-scale, system intensity, land tenure, importance of livestock etc.)

5. Socio-cultural aspects	
5.1 Where does the farmers' know-how come from? Who is trusted to change practices?	Beliefs around crop management techniques
6. Drought	
6.1 What is the impact of drought on crop yields and marketing, compared to good and normal years?	Refer to the last 3 years (drought in 2013/14) Consider grain and residues
6.2 What is the impact of drought on livestock health and prices?	
6.3 How do farmers cope with droughts?	Livestock sales, other CR use etc.
6.4 What is the impact of drought on the CR economic value and CR use strategy?	Contribution to family incomes Plot rented to pastoralists for grazing More straw sales, higher price
7. Time preferences and strategies	
7.1 When a farmer plans his activities, how many seasons / years does he consider?	
7.2 How flexible farmers are, to change practices throughout a season or across years?	

Annex III – Household survey template

HOUSEHOLD SURVEY

1. Farmer information

1.1 Name		1.2 Age	
1.3 Community	□ Beni Khirane □ Sma'ala □ Other ___________	1.4 Commune	

2. Agricultural overview

2.1 In your household, how many members participate at least partially to farm work?			
2.2 Have you been involved in the INRA/ICARDA project? (Tick one)	□ Onsite trials throughout the project □ Onsite trials but I withdrew □ I attended some workshops □ None		
2.3 Are you member of a farmers' organization?	□ Yes □ No	2.4 If "Yes", which one(s)? (Tick one or two)	□ Al Baraka □ Cooperative Essayd □ Essmayla □ Other _____________
2.5 What area did you cultivate in 2015? (ha, one decimal)			
2.6 What are your land rights over this land? (Tick one or several)	□ Full ownership (*melk taam*) undivided □ Indirect (rent or cooperative) □ Full ownership (*melk taam*) divided □ Other ________________ □ Individualized collective land (*melk al manfa*)		

2.7 How did you use this land in 2014-2015? (ha, one decimal)	2.7.1 Bread wheat		2.7.5 Oat grain		2.7.9 Maize		2.7.13 Weedy fallow		
	2.7.2 Durum wheat		2.7.6 Oat fodder		2.7.10 Potato		2.7.14 Rangeland		
	2.7.3 Barley		2.7.7 Forage pea		2.7.11 Medicago		2.7.15 Other _________		
	2.7.4 Triticale		2.7.8 Forage mixture		2.7.12 Pulses for human consumption				
2.8 What kind of rotation do you practice?	□ Quadrennial □ Triennial □ Biennial □ None								

3. Agricultural productivity

3.1 What is your bread wheat yield? (q/ha, one decimal)	3.1.1 In a normal year		3.1.2 In a good year		3.1.3 In a dry year	
3.2 What is your durum wheat yield? (q/ha, one decimal)	3.2.1 In a normal year		3.2.2 In a good year		3.2.3 In a dry year	
3.3 What is your barley yield? (q/ha, one decimal)	3.3.1 In a normal year		3.3.2 In a good year		3.3.3 In a dry year	
3.4 What is the price of 1 quintal of your bread wheat	3.4.1 In a normal year		3.4.2 In a good year		3.4.3 In a dry year	

sold on the market? (MAD/q)							
3.5 What is the price of 1 quintal of your durum wheat sold on the market? (MAD/q)	3.5.1 In a normal year		3.5.2 In a good year		3.5.3 In a dry year		
3.6 What is the price of 1 quintal of your barley sold on the market? (MAD/q)	3.6.1 In a normal year		3.6.2 In a good year		3.6.3 In a dry year		
3.7 In a dry year, how is the production managed?	3.7.1 Bread wheat	□ Reaped □ Grazed □ Depending on the plot	3.7.2 Durum wheat	□ Reaped □ Grazed □ Depending on the plot	3.7.3 Barley	□ Reaped □ Grazed □ Depending on the plot	

4. Crop residues production

4.1 How much bread wheat straw do you produce? (bale/ha)	4.1.1 In a normal year		4.1.2 In a good year		4.1.3 In a dry year	
4.2 How much durum wheat straw do you produce? (bale/ha)	4.2.1 In a normal year		4.2.2 In a good year		4.2.3 In a dry year	
4.3 How much barley straw do you produce? (bale/ha)	4.3.1 In a normal year		4.3.2 In a good year		4.3.3 In a dry year	
4.4 What quantity of residues from other crops do you produce? (q/ha, or "?" if not known)	4.4.1 In a normal year		4.4.2 In a good year		4.4.3 In a dry year	
4.5 How much stubble do you produce? (indicate unit: a/ equivalent days of grazing for a 20-sheep flock or b/quintals)	4.5.1 In a normal year		4.5.2 In a good year		4.5.3 In a dry year	
4.6 Do you use the following machinery for residues?	4.6.1 Baler	□ Yes □ No	4.6.2 Rotavator or râteau-faneur	□ Yes □ No		
4.7 At what height do you cut straw? (cm)	4.7.1 In a normal year		4.7.2 In a good year		4.7.3 In a dry year	
4.8 How many passes do you use the baler for?	□ 2 □ 1					
4.9 What are the costs of straw baling? (MAD/bale)	4.9.1 Baler		4.9.2 Transport		4.9.3 Stack construction	
4.10 Do you practice summer stubble plowing?	□ Yes □ No	4.11 If 4.10 = 'Yes', with which tool?	□ Machinery □ Manual			
4.12 What is the cost of stubble plowing? (MAD/ha)						
4.13 When you select a seed variety, what drives your choice?	4.13.1 First factor	□ Grain yield □ Straw yield □ Seed price □ Market availability □ Other __________	4.13.2 Second factor	□ Grain yield □ Straw yield □ Seed price □ Market availability □ Other ____________		
4.14 Do you maintain a high seeding rate to increase the volume of biomass produced for some of your crops?	□ Yes □ No					

5. Crop residues use

5.1 What degree of control over your crop residues do you think you have? (Tick one)	□ Optimal □ Medium □ Low					
5.2 In a normal or good year, out of 10 units of	5.2.1 Stall feeding		5.2.3 Trade		5.2.5 Onsite grazing	

straw, how much do you use for … ? (whole number)	5.2.2 Shed or poultry bedding		5.2.4 Left on soil		5.2.6 Construction & other	
5.3 In a dry year, out of 10 units of straw, how much do you use for … ? (whole number)	5.3.1 Stall feeding		5.3.3 Trade		5.3.5 Onsite grazing	
	5.3.2 Shed or poultry bedding		5.3.4 Left on soil		5.3.6 Construction & other	
5.4 In a normal or good year, how much stubble do you use for … ? (rough %, '?' if he doesn't know)	5.4.1 Grazing by own flock		5.4.3 Left on soil		5.4.5 Incorporation in soil	
	5.4.2 Grazing by other flock		5.4.4 Amendment		5.4.6 Construction & other	
5.5 In a dry year, how much stubble do you use for … ? (rough %)	5.5.1 Grazing by own flock		5.5.3 Left on soil		5.5.5 Incorporation in soil	
	5.5.2 Grazing by other flock		5.5.4 Amendment		5.5.6 Construction & other	

5.6 In general, how are crop residues managed on remote plots, compared to closer plots?	☐ More collection ☐ More grazing ☐ More cover ☐ No difference
5.7 In general, how are crop residues managed on steep plots (*harch*), compared to flat plots (*gaada*)?	☐ More collection ☐ More grazing ☐ More cover ☐ No difference

5.8 What is the average price of wheat straw? (MAD/bale)	5.8.1 In a normal year		5.8.2 In a good year		5.8.3 In a dry year	
5.9 What is the average price of barley straw? (MAD/bale)	5.9.1 In a normal year		5.9.2 In a good year		5.9.3 In a dry year	
5.10 What is the minimum price at which it is worth it to sell straw? (MAD/bale)	5.10.1 Wheat		5.10.2 Barley			
5.11 Where or to whom do you sell straw?	☐ Retailers ☐ Local market ☐ Market in other region ☐ Directly to farmers ☐ Other ___________					
5.12 How long can you store straw for feeding purpose? (Tick one)	☐ < 6 months ☐ 6 to 12 months ☐ 1 to 2 years ☐ > 2 years					
5.13 How much do you rent a plot to a shepherd for 1 week of stubble grazing? (MAD/ha)	5.13.1 In a normal year		5.13.2 In a good year		5.13.3 In a dry year	

6. Importance of livestock

6.1 What do you perceive as most important?	☐ Livestock ☐ Crops ☐ Both are equal					
6.2 Could you rank the contribution of the following sectors to your yearly food & cash incomes? (from 1 to 4)	6.2.1 Livestock		6.2.3 Off-farm			
	6.2.2 Crops		6.2.4 Remittances			
6.3 How many sheep do you have in 2015?	6.3.1 Ewes		6.3.2 Fattening sheep		6.3.3 Rams	
6.4 How many goats do you have?			6.5 How many cows do you have?			
6.6 How many horses do you have?			6.7 How many donkeys do you have?			
6.8 Even with feed changes, do you notice an increase in the livestock mortality rates in dry years?	☐ Sharp increase ☐ Moderate increase ☐ No change					
6.9 On average, how does the selling price of animals increase or decrease	6.9.1 Ewe		6.9.2 Lamb			

in a dry year compared to a normal year? (rough %, indicate + or -)	6.9.3 Goat		6.9.4 Cattle	

7. Livestock feeding

7.1 How do you feed your ewes in a normal or good year?	7.1.1 Cereals straw - From		7.1.2 Cereals straw - # weeks		7.1.13 Rangeland grazing – From		7.1.14 Rangeland grazing - # weeks	
	7.1.3 Cereals stubble – From		7.1.4 Cereals stubble - # weeks		7.1.15 Forage grazing - From		7.1.16 Forage grazing - # weeks	
	7.1.5 Cereals grain – From		7.1.6 Cereals grain - # weeks		7.1.17 Forage hay – From		7.1.18 Forage hay - # weeks	
	7.1.7 Cereals bran – From		7.1.8 Cereals bran - # weeks		7.1.19 Maize stover – From		7.1.20 Maize stover - # weeks	
	7.1.9 Concentrate – From		7.1.10 Concentrate - # weeks		7.1.21 Pulses residues - From		7.1.22 Pulses residues - # weeks	
	7.1.11 Fallow grazing - From		7.1.12 Fallow grazing - # weeks		7.1.23 Other ______ - From		7.1.24 Other ______ - # weeks	
7.2 How do you feed your rams in a normal or good year?	7.2.1 Cereals straw - From		7.2.2 Cereals straw - # weeks		7.2.13 Rangeland grazing – From		7.2.14 Rangeland grazing - # weeks	
	7.2.3 Cereals stubble – From		7.2.4 Cereals stubble - # weeks		7.2.15 Forage grazing - From		7.2.16 Forage grazing - # weeks	
	7.2.5 Cereals grain – From		7.2.6 Cereals grain - # weeks		7.2.17 Forage hay – From		7.2.18 Forage hay - # weeks	
	7.2.7 Cereals bran – From		7.2.8 Cereals bran - # weeks		7.2.19 Maize stover – From		7.2.20 Maize stover - # weeks	
	7.2.9 Concentrate – From		7.2.10 Concentrate - # weeks		7.2.21 Pulses residues - From		7.2.22 Pulses residues - # weeks	
	7.2.11 Fallow grazing - From		7.2.12 Fallow grazing - # weeks		7.2.23 Other ______ - From		7.2.24 Other ______ - # weeks	
7.3 How do you feed your lambs in a normal or good year?	7.3.1 Cereals straw - From		7.3.2 Cereals straw - # weeks		7.3.13 Rangeland grazing – From		7.3.14 Rangeland grazing - # weeks	
	7.3.3 Cereals stubble – From		7.3.4 Cereals stubble - # weeks		7.3.15 Forage grazing - From		7.3.16 Forage grazing - # weeks	
	7.3.5 Cereals grain – From		7.3.6 Cereals grain - # weeks		7.3.17 Forage hay – From		7.3.18 Forage hay - # weeks	
	7.3.7 Cereals bran – From		7.3.8 Cereals bran - # weeks		7.3.19 Maize stover – From		7.3.20 Maize stover - # weeks	
	7.3.9 Concentrate – From		7.3.10 Concentrate - # weeks		7.3.21 Pulses residues - From		7.3.22 Pulses residues - # weeks	
	7.3.11 Fallow grazing - From		7.3.12 Fallow grazing - # weeks		7.3.23 Other ______ - From		7.3.24 Other ______ - # weeks	
7.4 How do you feed your goats in a normal or good year?	7.4.1 Cereals straw - From		7.4.2 Cereals straw - # weeks		7.4.13 Rangeland grazing – From		7.4.14 Rangeland grazing - # weeks	
	7.4.3 Cereals stubble – From		7.4.4 Cereals stubble - # weeks		7.4.15 Forage grazing - From		7.4.16 Forage grazing - # weeks	
	7.4.5 Cereals grain – From		7.4.6 Cereals grain - # weeks		7.4.17 Forage hay – From		7.4.18 Forage hay - # weeks	
	7.4.7 Cereals bran – From		7.4.8 Cereals bran - # weeks		7.4.19 Maize stover – From		7.4.20 Maize stover - # weeks	
	7.4.9 Concentrate – From		7.4.10 Concentrate - # weeks		7.4.21 Pulses residues - From		7.4.22 Pulses residues - # weeks	
	7.4.11 Fallow grazing - From		7.4.12 Fallow grazing - # weeks		7.4.23 Other ______ - From		7.4.24 Other ______ - # weeks	
7.5 How do you feed your cattle	7.5.1 Cereals straw - From		7.5.2 Cereals straw - # weeks		7.5.13 Rangeland grazing – From		7.5.14 Rangeland grazing - # weeks	
	7.5.3 Cereals stubble – From		7.5.4 Cereals stubble - # weeks		7.5.15 Forage grazing - From		7.5.16 Forage grazing - # weeks	
	7.5.5 Cereals grain – From		7.5.6 Cereals grain - # weeks		7.5.17 Forage hay – From		7.5.18 Forage hay - # weeks	

in a normal or good year?	7.5.7 Cereals bran – From		7.5.8 Cereals bran - # weeks		7.5.19 Maize stover – From		7.5.20 Maize stover - # weeks	
	7.5.9 Concentrate – From		7.5.10 Concentrate - # weeks		7.5.21 Pulses residues - From		7.5.22 Pulses residues - # weeks	
	7.5.11 Fallow grazing - From		7.5.12 Fallow grazing - # weeks		7.5.23 Other ______ - From		7.5.24 Other ______ - # weeks	
7.6 How do you feed your horses in a normal or good year?	7.6.1 Cereals straw - From		7.6.2 Cereals straw - # weeks		7.6.13 Rangeland grazing – From		7.6.14 Rangeland grazing - # weeks	
	7.6.3 Cereals stubble – From		7.6.4 Cereals stubble - # weeks		7.6.15 Forage grazing - From		7.6.16 Forage grazing - # weeks	
	7.6.5 Cereals grain – From		7.6.6 Cereals grain - # weeks		7.6.17 Forage hay – From		7.6.18 Forage hay - # weeks	
	7.6.7 Cereals bran – From		7.6.8 Cereals bran - # weeks		7.6.19 Maize stover – From		7.6.20 Maize stover - # weeks	
	7.6.9 Concentrate – From		7.6.10 Concentrate - # weeks		7.6.21 Pulses residues - From		7.6.22 Pulses residues - # weeks	
	7.6.11 Fallow grazing - From		7.6.12 Fallow grazing - # weeks		7.6.23 Other ______ - From		7.6.24 Other ______ - # weeks	
7.7 How do you feed your donkeys in a normal or good year?	7.7.1 Cereals straw - From		7.7.2 Cereals straw - # weeks		7.7.13 Rangeland grazing – From		7.7.14 Rangeland grazing - # weeks	
	7.7.3 Cereals stubble – From		7.7.4 Cereals stubble - # weeks		7.7.15 Forage grazing - From		7.7.16 Forage grazing - # weeks	
	7.7.5 Cereals grain – From		7.7.6 Cereals grain - # weeks		7.7.17 Forage hay – From		7.7.18 Forage hay - # weeks	
	7.7.7 Cereals bran – From		7.7.8 Cereals bran - # weeks		7.7.19 Maize stover – From		7.7.20 Maize stover - # weeks	
	7.7.9 Concentrate – From		7.7.10 Concentrate - # weeks		7.7.21 Pulses residues - From		7.7.22 Pulses residues - # weeks	
	7.7.11 Fallow grazing - From		7.7.12 Fallow grazing - # weeks		7.7.23 Other ______ - From		7.7.24 Other ______ - # weeks	
7.8 How do you feed your ewes in a dry year?	7.8.1 Cereals straw - From		7.8.2 Cereals straw - # weeks		7.8.13 Rangeland grazing – From		7.8.14 Rangeland grazing - # weeks	
	7.8.3 Cereals stubble – From		7.8.4 Cereals stubble - # weeks		7.8.15 Forage grazing - From		7.8.16 Forage grazing - # weeks	
	7.8.5 Cereals grain – From		7.8.6 Cereals grain - # weeks		7.8.17 Forage hay – From		7.8.18 Forage hay - # weeks	
	7.8.7 Cereals bran – From		7.8.8 Cereals bran - # weeks		7.8.19 Maize stover – From		7.8.20 Maize stover - # weeks	
	7.8.9 Concentrate – From		7.8.10 Concentrate - # weeks		7.8.21 Pulses residues - From		7.8.22 Pulses residues - # weeks	
	7.8.11 Fallow grazing - From		7.8.12 Fallow grazing - # weeks		7.8.23 Other ______ - From		7.8.24 Other ______ - # weeks	
7.9 How do you feed your rams in a dry year?	7.9.1 Cereals straw - From		7.9.2 Cereals straw - # weeks		7.9.13 Rangeland grazing – From		7.9.14 Rangeland grazing - # weeks	
	7.9.3 Cereals stubble – From		7.9.4 Cereals stubble - # weeks		7.9.15 Forage grazing - From		7.9.16 Forage grazing - # weeks	
	7.9.5 Cereals grain – From		7.9.6 Cereals grain - # weeks		7.9.17 Forage hay – From		7.9.18 Forage hay - # weeks	
	7.9.7 Cereals bran – From		7.9.8 Cereals bran - # weeks		7.9.19 Maize stover – From		7.9.20 Maize stover - # weeks	
	7.9.9 Concentrate – From		7.9.10 Concentrate - # weeks		7.9.21 Pulses residues - From		7.9.22 Pulses residues - # weeks	
	7.9.11 Fallow grazing - From		7.9.12 Fallow grazing - # weeks		7.9.23 Other ______ - From		7.9.24 Other ______ - # weeks	
7.10 How do you feed your fattening lambs in a	7.10.1 Cereals straw - From		7.10.2 Cereals straw - # weeks		7.10.13 Rangeland grazing – From		7.10.14 Rangeland grazing - # weeks	
	7.10.3 Cereals stubble – From		7.10.4 Cereals stubble - # weeks		7.10.15 Forage grazing - From		7.10.16 Forage grazing - # weeks	
	7.10.5 Cereals grain – From		7.10.6 Cereals grain - # weeks		7.10.17 Forage hay – From		7.10.18 Forage hay - # weeks	
	7.10.7 Cereals bran – From		7.10.8 Cereals bran - # weeks		7.10.19 Maize stover – From		7.10.20 Maize stover - # weeks	
	7.10.9 Concentrate – From		7.10.10 Concentrate - # weeks		7.10.21 Pulses residues - From		7.10.22 Pulses residues - # weeks	

dry year?	7.10.11 Fallow grazing - From		7.10.12 Fallow grazing - # weeks		7.10.23 Other ______ - From		7.10.24 Other ______ - # weeks	
7.11 How do you feed your goats in a dry year?	7.11.1 Cereals straw - From		7.11.2 Cereals straw - # weeks		7.11.13 Rangeland grazing – From		7.11.14 Rangeland grazing - # weeks	
	7.11.3 Cereals stubble – From		7.11.4 Cereals stubble - # weeks		7.11.15 Forage grazing - From		7.11.16 Forage grazing - # weeks	
	7.11.5 Cereals grain – From		7.11.6 Cereals grain - # weeks		7.11.17 Forage hay – From		7.11.18 Forage hay - # weeks	
	7.11.7 Cereals bran – From		7.11.8 Cereals bran - # weeks		7.11.19 Maize stover – From		7.11.20 Maize stover - # weeks	
	7.11.9 Concentrate – From		7.11.10 Concentrate - # weeks		7.11.21 Pulses residues - From		7.11.22 Pulses residues - # weeks	
	7.11.11 Fallow grazing - From		7.11.12 Fallow grazing - # weeks		7.11.23 Other ______ - From		7.11.24 Other ______ - # weeks	
7.12 How do you feed your cattle in a dry year?	7.12.1 Cereals straw - From		7.12.2 Cereals straw - # weeks		7.12.13 Rangeland grazing – From		7.12.14 Rangeland grazing - # weeks	
	7.12.3 Cereals stubble – From		7.12.4 Cereals stubble - # weeks		7.12.15 Forage grazing - From		7.12.16 Forage grazing - # weeks	
	7.12.5 Cereals grain – From		7.12.6 Cereals grain - # weeks		7.12.17 Forage hay – From		7.12.18 Forage hay - # weeks	
	7.12.7 Cereals bran – From		7.12.8 Cereals bran - # weeks		7.12.19 Maize stover – From		7.12.20 Maize stover - # weeks	
	7.12.9 Concentrate – From		7.12.10 Concentrate - # weeks		7.12.21 Pulses residues - From		7.12.22 Pulses residues - # weeks	
	7.12.11 Fallow grazing - From		7.12.12 Fallow grazing - # weeks		7.12.23 Other ______ - From		7.12.24 Other ______ - # weeks	
7.13 How do you feed your horses in a dry year?	7.13.1 Cereals straw - From		7.13.2 Cereals straw - # weeks		7.13.13 Rangeland grazing – From		7.13.14 Rangeland grazing - # weeks	
	7.13.3 Cereals stubble – From		7.13.4 Cereals stubble - # weeks		7.13.15 Forage grazing - From		7.13.16 Forage grazing - # weeks	
	7.13.5 Cereals grain – From		7.13.6 Cereals grain - # weeks		7.13.17 Forage hay – From		7.13.18 Forage hay - # weeks	
	7.13.7 Cereals bran – From		7.13.8 Cereals bran - # weeks		7.13.19 Maize stover – From		7.13.20 Maize stover - # weeks	
	7.13.9 Concentrate – From		7.13.10 Concentrate - # weeks		7.13.21 Pulses residues - From		7.13.22 Pulses residues - # weeks	
	7.13.11 Fallow grazing - From		7.13.12 Fallow grazing - # weeks		7.13.23 Other ______ - From		7.13.24 Other ______ - # weeks	
7.14 How do you feed your donkeys in a dry year?	7.14.1 Cereals straw - From		7.14.2 Cereals straw - # weeks		7.14.13 Rangeland grazing – From		7.14.14 Rangeland grazing - # weeks	
	7.14.3 Cereals stubble – From		7.14.4 Cereals stubble - # weeks		7.14.15 Forage grazing - From		7.14.16 Forage grazing - # weeks	
	7.14.5 Cereals grain – From		7.14.6 Cereals grain - # weeks		7.14.17 Forage hay – From		7.14.18 Forage hay - # weeks	
	7.14.7 Cereals bran – From		7.14.8 Cereals bran - # weeks		7.14.19 Maize stover – From		7.14.20 Maize stover - # weeks	
	7.14.9 Concentrate – From		7.14.10 Concentrate - # weeks		7.14.21 Pulses residues - From		7.14.22 Pulses residues - # weeks	
	7.14.11 Fallow grazing - From		7.14.12 Fallow grazing - # weeks		7.14.23 Other ______ - From		7.14.24 Other ______ - # weeks	

7.15 In a normal year, how much feed do you need for your herd in total (including fattening)? (quintal, indicate unit if different)	7.15.1 Barley grain		7.15.7 Bran	
	7.15.2 Barley green fodder		7.15.8 Straw	
	7.15.3 Oat grain		7.15.9 Forage hay (pea, vetch …)	
	7.15.4 Oat green fodder		7.15.10 Fallow hay	
	7.15.5 Triticale		7.15.11 Sugar beet pulp	

	7.15.6 Maize		7.15.12 Other ___________	
7.16 How much do you spend for feed (not produced) in a normal year? (MAD/kg or indicate unit if different)	7.16.1 Barley grain		7.16.7 Bran	
	7.16.2 Barley green fodder		7.16.8 Straw	
	7.16.3 Oat grain		7.16.9 Forage hay (pea, vetch …)	
	7.16.4 Oat green fodder		7.16.10 Fallow hay	
	7.16.5 Triticale		7.16.11 Sugar beet pulp	
	7.16.6 Maize		7.16.12 Other ___________	

7.17 Do you pay grazing rights?	◻ Yes ◻ No ◻ Sometimes	7.18 If 7.17='Yes', for what kind of grazing? (Tick one or more)	◻ Stubble ◻ Fallow ◻ Rangeland	7.19 If 7.17='Yes', how much do you pay per year? (MAD)	

7.20 Do you think you could increase feed alternatives to cereals residues in the future (forage mixtures, fodder, by-products)? (Tick one)	◻ Yes, surely ◻ Yes, perhaps ◻ No ◻ I don't know

7.21 Could you rank your three main constraints to the uptake or expansion of these feed alternatives? (from 1 to 3)	7.21.1 Lack of technical knowledge & support to shift		7.21.5 Production costs (seeds …)	
	7.21.2 Doubts on productive potential		7.21.6 Uncertainty of economic benefits	
	7.21.3 Doubts on nutritive value		7.21.7 Labour requirements	
	7.21.4 Lack of land		7.21.8 By-products availability on markets	

7.22 What is the main advantage of cereal residues as feed? (Tick one)	◻ Easy access ◻ Low cost ◻ Nutritional value ◻ Fiber content ◻ Other ___________

8. Attitude towards conservation agriculture

8.1 What kind of tillage do you practice? (Tick one)	◻ No or minimum tillage ◻ Conventional tillage ◻ Mixed
8.2 If 8.1='conventional tillage', have you heard of no tillage?	◻ Yes, I know what it is ◻ Yes but I'm not sure what it is ◻ No

8.3 Could you rank the two main constraints to the adoption or expansion of no tillage in your farm? (from 1 to 2)	8.3.1 Doubts on benefits for soil & plants		8.3.4 No-till seeder cost	
	8.3.2 Lack of knowledge & support to shift		8.3.5 Increased herbicides cost	
	8.3.3 No-till seeder availability		8.3.6 Other _______________	

8.4 Do you have experience with purposely keeping more residues on croplands after harvest? (Tick one)	◻ Personal experience ◻ Other farmers ◻ None

8.5 Which of the following statements referring to potential benefits of maintaining more residues do you agree with? (Tick one per statement)	8.5.1 It helps reduce erosion	◻ Yes ◻ No ◻ I don't know
	8.5.2 It increases organic matter in the soil	◻ Yes ◻ No ◻ I don't know
	8.5.3 It enhances soil moisture	◻ Yes ◻ No ◻ I don't know
	8.5.4 It enhances soil structure	◻ Yes ◻ No ◻ I don't know
	8.5.5 It helps decrease the costs of residues collection	◻ Yes ◻ No ◻ I don't know
	8.5.6 It requires less labour for residues collection	◻ Yes ◻ No ◻ I don't know

	8.5.7 When more residues are left on some parts of the plot, the yield is better the year after	□ Yes □ No □ I don't know
8.6 Which of the following statements referring to potential shortcomings of maintaining more residues do you agree with? (Tick one per statement)	8.6.1 There is no realistic feed alternative to residues	□ Yes □ No □ I don't know
	8.6.2 Residues would increase weeds and risks of diseases	□ Yes □ No □ I don't know
	8.6.3 Residues intercept water thus impede water infiltration	□ Yes □ No □ I don't know
	8.6.4 Maintaining residues would increase herbicides needs	□ Yes □ No □ I don't know
	8.6.5 Without residues grazing, there is no animal manure supply	□ Yes □ No □ I don't know
	8.6.6 Residues are not convenient for the seeder usage (clogging)	□ Yes □ No □ I don't know
	8.6.7 Whatever the benefits, the economic value of straw is too high	□ Yes □ No □ I don't know
8.7 In case you retain more cereal residues on the soil, what maximum percentage of retention would seem acceptable for you? (Tick one)		□ 15% □ 30% □ 50% □ > 50% □ I don't know
8.8 In case you retain more cereal residues on the soil, would you afford to apply more chemical fertilizers in the first 3 years? (Tick one)		□ Yes, all plots □ Yes, few plots □ No □ I don't know
8.9 In case you retain more cereal residues on the soil, would you afford to apply more herbicides before sowing? (Tick one)		□ Yes, all plots □ Yes, few plots □ No □ I don't know

8.10 What are the two more important factors that influence your own decision to use a specific farming practice? (from 1 to 2)	8.10.1 Family / traditional know-how		8.10.7 Reducing labour requirements	
	8.10.2 What the neighbours do		8.10.8 Reducing production costs	
	8.10.3 My personal experience		8.10.9 Mitigating drought risk	
	8.10.4 Gaining time and flexibility		8.10.10 Not harming environment	
	8.10.5 Maximizing returns for livestock		8.10.11 Fitting market trends	
	8.10.6 Maximizing crop yields		8.10.12 Other ________	

9. LAND AND GRAZING ISSUES

9.1 Do you feel that you are limited in your farm investments by your land rights?	□ Yes □ No □ I don't know
9.2 Do you witness unconsented grazing on your plots after harvest?	□ Yes, regularly □ Yes, from time to time □ No
9.3 In case you retain more cereal residues on the soil, could you protect your plot from free grazing?	□ Yes □ No □ I don't know
9.4 If 9.3 = 'Yes', how would you do that? (Tick one)	□ Agreement with neighbours & shepherds □ Hard fencing □ Live fencing

10. RISKS PERCEPTION

10.1 Do you think that your own land is affected by erosion?	□ Yes □ No □ I don't know

10.2 If 10.1 = 'Yes', how do you recognize it? (Tick one or several answers)	□ Rills □ Gullies □ Decreasing soil depth □ Soil compaction □ Poor soil aggregation □ Sediments downstream □ Flash floods
10.3 If 10.1 = 'Yes', how serious is this problem? (Tick one)	□ Very serious □ Moderately serious □ Not serious

10.4 Do you agree with the following statements referring to droughts? (Tick one)	10.4.1 Droughts are more and more frequent	□ Yes □ No □ I don't know
	10.4.2 Droughts are more and more acute	□ Yes □ No □ I don't know
	10.4.3 The overall amount of annual precipitation is decreasing	□ Yes □ No □ I don't know
	10.4.4 There are more and more rainfall variations between years	□ Yes □ No □ I don't know
	10.4.5 The distribution of rainfall through the crop cycle is becoming inadequate	□ Yes □ No □ I don't know
	10.4.6 Temperatures are becoming inadequate	□ Yes □ No □ I don't know

10.5 Do you think that this trend is going to continue in the coming decades?	□ Yes □ No □ I don't know
10.6 Do you think that climate change requires adjustments in agricultural practices in the future? (Tick one)	□ Yes, dramatic adjustments □ Yes, minor adjustments □ No □ I don't know

10.7 Could you rank what you perceive as the two most severe risks for your crops and livestock in the future? (1 or 2)	10.7.1 Droughts		10.7.5 Market turmoil	
	10.7.2 Other climatic disasters		10.7.6 Inputs price and availability	
	10.7.3 Land degradation & erosion		10.7.7 Livestock epidemics	
	10.7.4 Land disputes		10.7.8 Other ____________	
10.8 Could you rank what you perceive as the most likely risks for your crops and livestock in the future? (1 or 2)	10.8.1 Droughts		10.8.5 Market turmoil	
	10.8.2 Other climatic disasters		10.8.6 Inputs price and availability	
	10.8.3 Land degradation & erosion		10.8.7 Livestock epidemics	
	10.8.4 Land disputes		10.8.8 Other ____________	

10.9 We are going to play a game. In this game, we look at different future scenarios involving different farming practices having different impacts on yields and residues. Which practice would you prefer? (give cards to the respondent with the characteristics written in Arabic)

Choice experiment 1	*Practice 1*	*Practice 2*	*Choice experiment 2*	*Practice 1*	*Practice 2*
Highest grain yield	40% of the years	60% of the years	Highest grain yield (5 first years)	40% of the years	60% of the years
Risk of crop failure in dry year	High	Medium	Highest grain yield (after 5 years)	20% of the years	80% of the years
Residues availability	80%	50%	Residues availability (5 first years)	80%	50%
			Residues yield (after 5 years)	5 t.ha^{-1}	7 t.ha^{-1}
10.9.1 Respondent choice (tick one)	□ Practice 1 □ Practice 2		10.9.2 Respondent choice (tick one)	□ Practice 1 □ Practice 2	

10.10 When you invest in a new crop/breed, input (e.g. machine) or practice (e.g. conservation) that significantly changes your production system, when do you expect to be paid off? (Tick one)	□ The 1st year □ Before 3 years □ Before 6 years □ Before 10 years □ The profitability doesn't matter
10.11 In case the precipitation is predicted to be low or delayed at the beginning of the agricultural	□ Fairly flexible □ Limitedly flexible

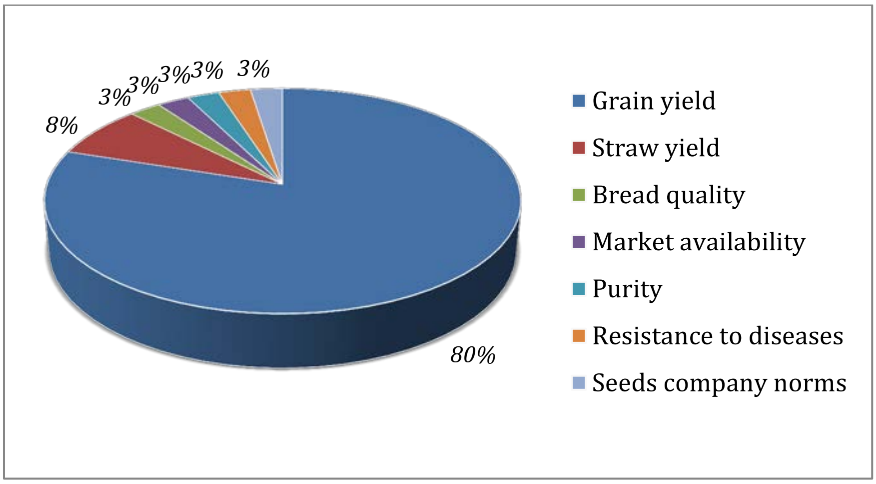
cycle, how flexible to adjust your plans and practices do you think you are? (Tick one)	□ Not flexible at all
10.12 In case you have some flexibility, what can you do? (Tick one or several answers)	□ Shift between crops & fallow □ Change in species or varieties □ Adjustment in inputs utilization □ Adjustment in land management practices □ Modification in the calendar □ Change in livestock feeding □ Other ________________________

6.2, 7.22, 8.3, 8.10, 10.7, 10.8, 10.9.1 and 10.9.2: give cards to the respondent with each option written in Arabic (ranking)

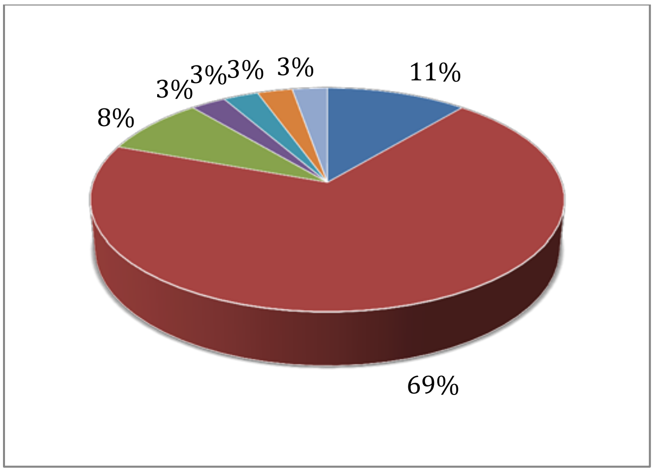
Annex IV – Household survey, List of respondents

#	Name	Community	No-till experience	Cropland	Flock size
001	Hicham Daouri	Beni Khirane	Involved in trials	> 10 ha	> 20 sheep
002	El Wafi Mohamed	Smaala	Involved in trials	> 10 ha	< 20 sheep
003	Chouqi Mustafa	Smaala	Involved in trials	> 10 ha	< 20 sheep
004	Mezzouine Mohamed	Smaala	CT	> 10 ha	> 20 sheep
005	Samir El Wafi	Smaala	Spontaneous NT adopters	< 10 ha	< 20 sheep
006	Qardaoui Mohamed	Smaala	CT	> 10 ha	> 20 sheep
007	Daoui Mhd Khouribish	Beni Khirane	Spontaneous NT adopters	> 10 ha	> 20 sheep
008	Berrishi Chaqi	Beni Khirane	Involved in trials	> 10 ha	> 20 sheep
009	Lamleh Mohamed	Beni Khirane	Spontaneous NT adopters	> 10 ha	> 20 sheep
010	Hassani Salah	Beni Khirane	CT	< 10 ha	< 20 sheep
011	Berishi Tarek	Beni Khirane	CT	< 10 ha	< 20 sheep
012	Chabli Mohamed	Beni Khirane	CT	> 10 ha	> 20 sheep
013	Hamid Berrishi	Beni Khirane	CT	> 10 ha	> 20 sheep
014	Moussaoui Mohamed	Beni Khirane	CT	< 10 ha	> 20 sheep
015	Daoui Chauqi	Beni Khirane	Involved in trials	> 10 ha	> 20 sheep
016	Lamleh Taïbi	Beni Khirane	Spontaneous NT adopters	> 10 ha	> 20 sheep
017	Berishi Otman	Beni Khirane	CT	< 10 ha	< 20 sheep
018	Hassani ??	Beni Khirane	CT	< 10 ha	< 20 sheep
019	Essayd Abdelmajid	Smaala	CT	< 10 ha	> 20 sheep
020	Abaya Ahmed	Smaala	CT	> 10 ha	< 20 sheep
021	Berishi Aziz	Smaala	CT	< 10 ha	< 20 sheep
022	Berhail Maati	Smaala	CT	< 10 ha	> 20 sheep
023	Berhail Waza	Smaala	CT	< 10 ha	< 20 sheep
024	Madani Abslam	Smaala	CT	< 10 ha	< 20 sheep
025	Belhamra Mohamed	Smaala	Dropped trials	> 10 ha	< 20 sheep
026	Berhail Mustafa	Smaala	CT	> 10 ha	> 20 sheep
027	Tarah Idriss	Beni Khirane	CT	< 10 ha	> 20 sheep
028	Daouri Abderrahim	Beni Khirane	CT	> 10 ha	> 20 sheep
029	Lamleh Mohamed	Beni Khirane	CT	> 10 ha	> 20 sheep
030	Boushta Said	Beni Khirane	CT	> 10 ha	> 20 sheep
031	El Faci Nordi	Smaala	CT	> 10 ha	< 20 sheep
032	El Goumri Mohamed	Smaala	CT	> 10 ha	> 20 sheep
033	Nordine Elyadine	Smaala	Involved in trials	> 10 ha	> 20 sheep
034	Mansouri Mohamed	Smaala	CT	< 10 ha	< 20 sheep
035	El Goumri Al Mardi	Smaala	CT	< 10 ha	< 20 sheep
036	Zaidi Salah	Smaala	CT	< 10 ha	< 20 sheep
037	Goumri Ahmed	Smaala	CT	< 10 ha	< 20 sheep
038	Fesraoui Mohamed	Smaala	CT	> 10 ha	< 20 sheep
039	Chtaibi Salah	Smaala	CT	> 10 ha	> 20 sheep
040	Hakimi Ali	Smaala	CT	> 10 ha	> 20 sheep

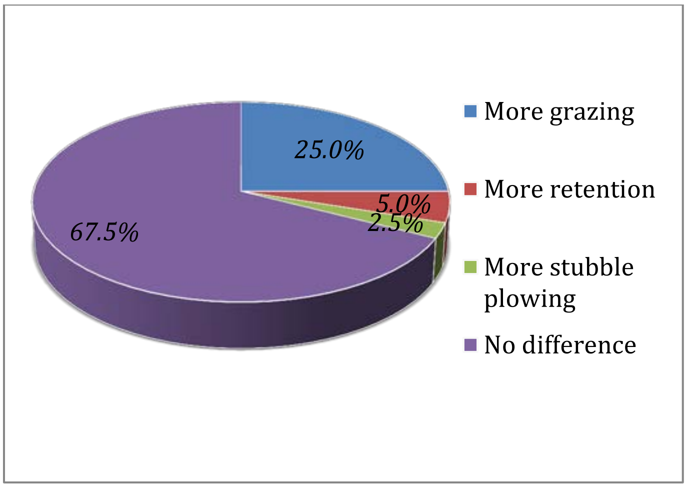
Annex V – Additional figures



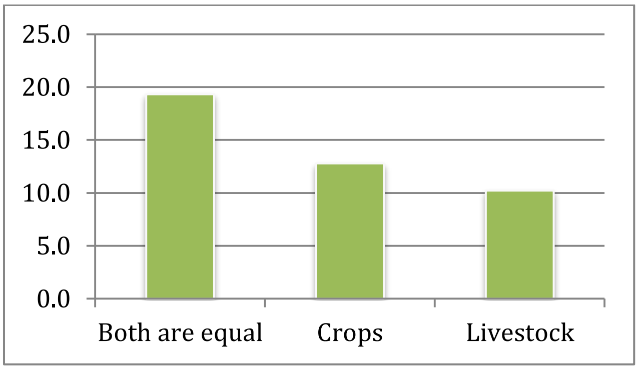
First factor of variety selection (% of respondents)



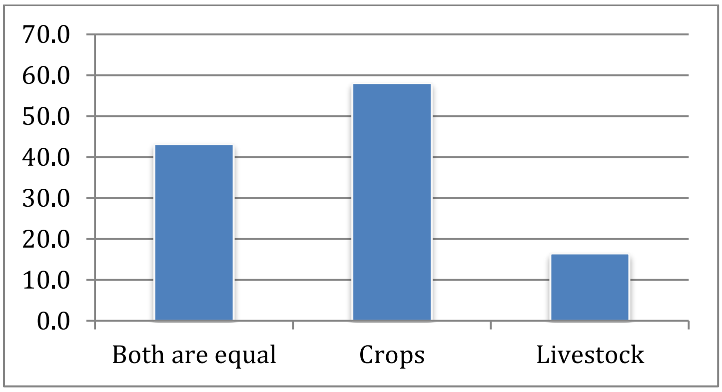
Second factor of variety selection (% of respondents)



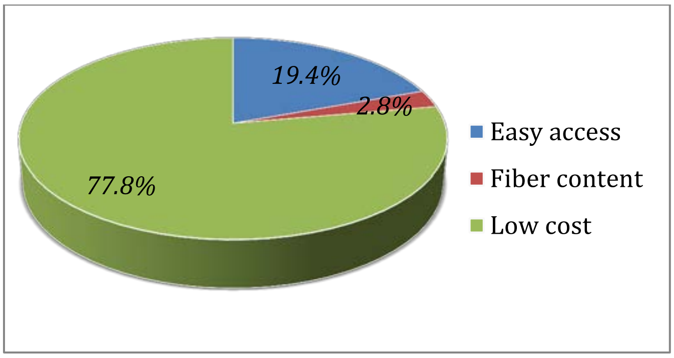
Management of crop residues in remote plots, compared to close plots (% of respondents)



Average flock size (TLU) and most important production system



Average cultivated area (ha) and most important production system



Perceived advantage of crop residues for feed (% of respondents)

Component matrix with factors loadings for each variable to the components obtained through factor analysis (highest loadings in bold)

Variable	1	2	3	4	5	6	7
Age	.225	-.210	-.054	.496	-.382	.056	.127
Cultivated area 2015	**.747**	-.440	-.071	.192	.068	.324	-.091
Ratio fallow-leguminous / cereals	-.248	.140	-.392	.191	.347	.311	-.290
Barley grain yield (normal year)	.347	.230	.112	-.382	.192	-.370	.079
Barley straw yield (normal year)	.362	.009	-.125	.273	.361	**-.605**	-.133
Height straw cut (normal year)	.062	.134	.488	.285	-.366	-.168	-.027
Stubble left on soil (normal year)	.158	**.684**	-.373	.237	.022	.094	.216
Crop residues contribution to cereal incomes (normal year)	.313	-.231	-.244	.496	.296	-.341	.340
Crop residues contribution to cereal incomes (dry year)	.214	-.093	.082	-.262	.015	-.226	**.810**
Crop residues net incomes (normal year)	**.692**	-.458	-.112	.207	.082	.241	.004
Flock size	**.766**	-.198	.215	-.226	.165	.206	-.078
Number of fattened sheep	.521	-.177	.434	-.017	.374	.175	.193
Stocking rate	-.188	.113	**.613**	-.120	-.027	-.167	-.036
Feed expenditure (normal year)	-.049	.402	.378	-.036	.505	.176	-.090
Community	-.119	.335	.402	.537	-.107	.379	.030
Involvement in the CANA project	**.657**	.264	.188	-.159	-.436	.049	-.168
Organization membership	.424	.530	.393	-.019	-.047	.223	.175
Land rights	**.666**	.063	-.171	-.005	-.360	.132	-.150
Rotation	.299	-.069	.226	-.039	.484	.088	-.168
Tillage	.488	.511	-.395	-.233	-.100	.010	.109
Most important production system	-.520	-.208	.341	.387	.206	.149	.202
Sectors contributing to yearly incomes	-.321	-.584	.038	-.283	-.308	.341	.281
Unconsented grazing	-.189	-.211	-.126	-.539	.193	.284	-.059
Stubble ploughing	.146	-.403	.305	-.005	-.200	-.533	-.392