agriculture

MDPI

Article

Engaging Farmers in Climate Change Adaptation Planning: Assessing Intercropping as a Means to Support Farm Adaptive Capacity

Sari J Himanen [1,*], Hanna Mäkinen [2], Karoliina Rimhanen [3] and Riitta Savikko [1]

[1] Ecological Crop Science, Natural Resources and Bioproduction, Natural Resources Institute Finland (Luke), Lönnrotinkatu 5, Mikkeli FI-50100, Finland; riitta.savikko@luke.fi
[2] Agroecology, Natural Resources and Bioproduction, Natural Resources Institute Finland (Luke), Jokiniemenkuja 1, Vantaa FI-01300, Finland; hanna.makinen@luke.fi
[3] Agroecology, Natural Resources and Bioproduction, Natural Resources Institute Finland (Luke), Latokartanonkaari 9, Helsinki FI-00790, Finland; karoliina.rimhanen@luke.fi
* Correspondence: sari.himanen@luke.fi; Tel.: +35-829-532-6132

Academic Editors: Annelie Holzkämper and Sibylle Stöckli
Received: 30 March 2016; Accepted: 19 July 2016; Published: 29 July 2016

Abstract: Agriculture is one of the most vulnerable and adaptation-prone sources of livelihood facing climate change. Joint adaptation planning by farmers and researchers can help develop practically feasible and environmentally and economically sound adaptation actions as well as encourage the proactive building of farm adaptive capacity. Here, the perceptions of Finnish farmers and rural stakeholders regarding intercropping, the cultivation of two or more crop genotypes together in time and space, as a means to prepare for climate change, were collected in an open workshop. Our aim was to identify the potentials and challenges associated with intercropping, its role as an adaptation strategy, and in farm adaptive capacity. Qualitative analysis revealed better yield security, increased nutrient and protein self-sufficiency, soil conservation and maintenance, reduced pathogen pressure and regulation of water dynamics as the main perceived potentials of intercropping. Potentials relating to the farm economy and environment were also recognized. The main challenges associated with intercropping were related to the lack of information on crop variety performance and optimal yielding in mixtures, industry and policy requirements for seed purity, more complicated crop management and harvesting, and the economic risks associated with experimenting with novel mixtures. Nitrogen-fixing legumes; deep-rooted species, such as lucerne (*Medicago sativa* L.); special crops, such as herbs in forage mixtures; and autumn-sown winter oilseeds and cereals were highlighted as the most promising intercrops. Because the recognized potentials relate to the safeguarding of field cropping from anticipated climate change and the associated weather variability, we conclude that intercropping can serve as one adaptation strategy to strengthen the adaptive capacity of Finnish farms. However, assuring markets and policies that allow the development of intercropping, performing experiments to assess the benefits and implement options in practice, and providing farmers and farm advisors with more knowledge on the method represent the critical prerequisites for the broader adoption of intercropping.

Keywords: adaptation planning; adaptive capacity; climate change; ecological intensification; intercropping; legumes; yield security

1. Introduction

Agriculture is a major land use, using approximately 38% of the global land area [1]. Climate change impacts agriculture by the need to develop existing practices, including field cropping, to minimize greenhouse gas emissions and thus meet the mitigation targets for climate change [2].

Farmers must adapt to the impacts of climate change to secure sufficient food production for the growing world population [3]. Sustainable intensification, i.e., increasing productivity from existing agricultural lands while minimizing the negative environmental effects and ensuring the future needs of food production, has been proposed as a central means to restrict further land clearing for agriculture and transform agriculture and food systems to operate in a more sustainable way [4]. Both climate change mitigation and adaptation relate to the main resources used in agriculture: land, carbon and nitrogen, water and energy, which provide good potential for synergism in the solutions [5]. Developing 'climate-smart' solutions for agriculture refers to adopting practices that benefit both mitigation and adaptation, while ensuring the productivity and resilience of farming, including the economic aspects [6]. Campbell et al. [7] state sustainable intensification to be crucial for both mitigation and adaptation actions, with "all cases of climate smart agriculture invariably turning out to be cases of sustainable intensification". Improving agricultural soil quality and carbon storage via crop diversification, important for mitigation, adaptation and productivity, is one example of such a case [8].

While the concept of sustainable intensification harbours numerous ways to achieve climate-smart agriculture, method-oriented approaches have arisen to guide the transformations needed in practice. One of them is ecological intensification, which specifies that intensification is to be achieved with "the natural functionalities that ecosystems offer" and by "designing multifunctional agroecosystems that are both sustained by nature and sustainable in their nature" [9]. The approach emphasizes reducing the use of external inputs such as industrial fertilizers and pesticides that further pressurize the environment and climate. It builds on spatio-temporal functional diversification of the agroecosystem and the combination of crop species and traits that support and make better use of ecosystem services [10]. Furthermore, it emphasizes context-specific, actor-initiated, and locally bound solutions rather than any generalizable protocols [9].

Intercropping represents a within-field diversification strategy that is based on ecological intensification. It refers to the cultivation of two or more crops together in time and space, and it is an ancient practice of cropping that aims to maximize productivity per land area using only few external inputs [11]. The method allows for designing local genotype combinations and intercropping types (mixed, relay, strip or row) to target various goals, which makes the method interesting to be developed and employed more as a means of sustainable agriculture. Overyielding per land area is one of the often-reported benefits of intercropping, and it is potentiated by the enhanced utilization of growth resources: growing space, water, nutrients and light [11]. Diverse crop genotypes compete less with each other than identical genotypes. Leveraging ecosystem services such as the biological fixation of nitrogen [12] and facilitative interactions such as the associational resistance to pests and pathogens [13] reduces the use of agrochemicals in intercropping. Mixing genotypes may also stabilize yields [14] and thus contribute to food and feed security.

Yield advantage from intercropping has often been noted to be higher with low levels of nitrogen (e.g., [15]) or phosphorus [16]. Under high nitrogen fertilization, the yield gains from intercropping can be negligible (e.g., [15]), making the method less attractive. The type of intercropping, optimal densities of the intercrops and management need to be adjusted case by case [17] because low complementarity can lead to a lack of targeted, enhanced utilization of the growth resources by intercropping [18]. Facilitative and compensatory interactions between plants can dominate at high abiotic stress (e.g., [19]), further supporting the use of intercropping as a proactive adaptation action to protect yields from climate change-induced challenges. The increased productivity per acreage in intercropping can also contribute to higher soil organic matter accumulation and carbon sequestration [8], which is important for greenhouse gas mitigation in agriculture in low-carbon soils. Thus, the potential to achieve multiple benefits that relate to both the mitigation of and adaptation to climate change and general risk aversion via diversification makes intercropping a good candidate for a climate-smart cropping practice to be developed for use in many localities. However, the potentials and barriers for the uptake of novel forms of intercropping must be recognized if the method is to be considered for broader use in modern, monoculture-dominated agriculture. Raising awareness and increasing communication on the method among farmers, researchers, farm advisors and other rural stakeholders can help assess the associated benefits and risks and encourage the development of innovative intercropping solutions [20].

Farmers in the northern latitudes, such as in Finland, are predicted to face progressive climate change through a warming and lengthening growing season [21], reduced snow cover time [22], higher precipitation [23], and potentially increasing weather variability and extremes such as windiness, heavy rains and warm spells [24]. The main field crops in Finland vary in their yield responses to weather: spring cereals have shown the most sensitivity to drought and elevated temperatures, rapeseeds to pests and high temperature episodes, and forage and winter crops to mild-to-cold shifts over winter [25]. The potential impact of higher variability in weather on crop yields [26] along with increasing pest risks upon warming and the yield gains potentiated by longer growing seasons [27] emphasize the proactive adaptation and adaptive capacity of farmers. Adaptations stem from farm adaptive capacity [28]: the building of resourcefulness, social capital such as knowledge and networks, and the ability to act proactively [29,30]. Recognizing practically feasible and ecologically, socially and economically sustainable means to strengthen the adaptive capacity of farms is critical for enhancing their ability to cope with the adverse impacts brought about by climate change and the associated changes in the economy, policies and markets [3]. It is a challenge both for research to recognize how to support adaptation planning of farmers and for farmers to evaluate the pros and cons associated with the uptake of each adaptation action in the context of farm operations and the long-term goals for farm development. In addition, the decisions and actions of farmers ultimately decide how effectively climate change mitigation and adaptation actions are implemented in agriculture; thus, the participatory planning of proactive adaptation strategies is crucial [31]. The implementation of novel practices such as intercropping requires sufficient knowledge at use [32] and the belief about the benefits clearly exceeding the potential risks associated with altering the familiar practices used. Many targeted adaptation actions focus on a certain external pressure and then on investing in specific solutions, such as technology (irrigation systems, machinery), infrastructure (bioenergy, livestock housing) or securing structures (water regulation). However, case studies suggest that climate-smart solutions related to soil, water, nutrient and yield maintenance could be effective and implemented relatively easily by employing system understanding and agroecological knowledge and developing in-farm cropping practices and management [6,7]. A further benefit of assessing intercropping as such a climate-smart solution is that the method can be developed to suit various types of farms, and knowledge is the main asset needed for advancing [9]. Employing such methods rather than more intensive technology or other input-based strategies avoids the creation of an additional burden on the environment.

In this study, we aimed to gather perceptions of Finnish farmers and rural stakeholders on the main potentials and challenges associated with using intercropping for field crops, identify the most promising intercrops in northern agriculture, and determine the roles of actors in advancing intercropping. Our further objective was to engage farmers and rural stakeholders in assessing and developing adaptation strategies for agriculture to face climate change, with an emphasis on the role of intercropping in building the adaptive capacity of farms and in developing multi-benefit climate-smart actions. In Finland, mixing forage crops (grasses and legumes) and undersowing cereals with perennial grasses are the most common forms of intercropping to date; meanwhile, other types of intercropping and multi-species or cultivar-rich forage mixtures might help meet various production goals, including preparing for climate change. To our knowledge, there are no earlier studies on the perceptions and motivations of farmers on the use of intercropping and whether it might contribute to climate change adaptation in Finland. Thus, raising awareness on how to utilize and design intercropping might encourage the development of intercropping in practice. The following research questions were addressed: (1) what are the potentials recognized for intercropping as one adaptation strategy to build a better adaptive capacity of Finnish farms; (2) what are the most promising intercrops for use in Finland; and (3) what are the challenges for the implementation of intercropping as an adaptation strategy in practice in Finland? Our approach of using an actor workshop to address these questions aimed to allow for collective learning and the co-creation of knowledge, which is suited well for climate change adaptation planning [33].

2. Materials and Methods

The data of the study were collected in an open workshop held in November 2013 in Huittinen, southwest Finland, as part of a wider workshop series arranged by a Finnish national communication project on climate change (Climate change and countryside) targeted at farmers and other rural stakeholders. The workshop had the title of "Yield and Farming Security via Intercropping Now and in the Future", and it comprised six invited short presentations addressing different aspects of intercropping: (1) introduction on intercropping in general and its potential in climate change risk aversion; (2) forage mixtures; (3) intercropping in enhancing soil maintenance and the use of growth resources; (4) availability of seed mixtures; (5) marketing of mixtures; and (6) farmer experiences of intercropping in practice. They served to provide general information on the method and were then followed by a facilitated workshop discussion. Intercropping was restricted in the workshop to field crop and crop variety mixtures, i.e., agroforestry was excluded. The discussions addressed forage mixtures, legumes, cereals, oilseeds and special crops in intercropping, undersown crops and green manure, which reflect the main types of field cropping in Finland and thus the most familiar forms of intercropping for the participants. A total of 30 people, of which 13 were farmers, participated in the workshop. Other participants were officers (four people), representatives of business (4), researchers (3), farm advisors (2), rural developers (2), farm school teachers (1) and students (1). Some of the participants had double roles, e.g., having experience in both research and advising or farming as a second source of livelihood. Twenty of the participants were male, and ten were female. Four researchers acted as workshop facilitators.

The group discussion was facilitated using a three-step me–we–us method [34]. The method is a combination of the nominal group discussion technique and the brainstorming technique [35,36]. The method assures active participation by all (even those not keen to actively participate in joint discussions) because everyone first writes down their opinions on the given questions individually (part "me", ca. 5 min time allotted for this) (for the individual writing method see [37]). These opinions were then discussed in randomly formed, small buzz groups of two to three people (part "we", circa 5–10 min), and the ideas considered most important were then reported one group at a time to allow for joint discussion among all workshop participants (part "us", length circa 40 min) (for buzz group method see, e.g., [38]). In part "us", suggestions were also written in a flip chart to allow everyone to see and consider their importance along with the discussions. The dialogue allowed for instant feedback and the raising of novel, opposite or supporting perspectives. Step-wise saturation of views often follows. Because the workshop participants were introduced to the intercropping method by the introductory presentations, the outcome gained presents the results of the workshop as a group communication process rather than a collection of individual opinions.

The following questions were posed to the workshop participants:

1. What potentials and challenges do you see for using intercropping in future farming?
2. Which crops and traits are the most promising for use in intercropping?
3. Who should act and how to support wider uptake of intercropping?

The "us" part discussions were recorded and transcribed to facilitate qualitative analysis of the perceptions. All mentioned potentials and suggested challenges, the most promising intercrops and traits, and the key actors and actions for advancing intercropping were listed. In the qualitative analysis, these potentials and challenges were further organized under themes related to production, farm economy, building social capital, and environment. The workshop findings are discussed in relation to the perceived benefits and restrictions of using an intercropping as reported in earlier studies, and reflecting the operating environment of Finland, exemplifying northern European modern agriculture.

3. Results

3.1. Potentials and Challenges of Intercropping in Finland

Perceived potentials of using intercropping related mostly to crop production and farm economy, with additional social and environmental aspects (Figure 1). Intercropping was regarded as supporting self-sufficiency for protein and nutrients, improving soil quality and water regulation, advancing novel genotypes and allowing the reduced use of external inputs. The potential to reduce workload was identified for certain types of intercropping, e.g., cover cropping.

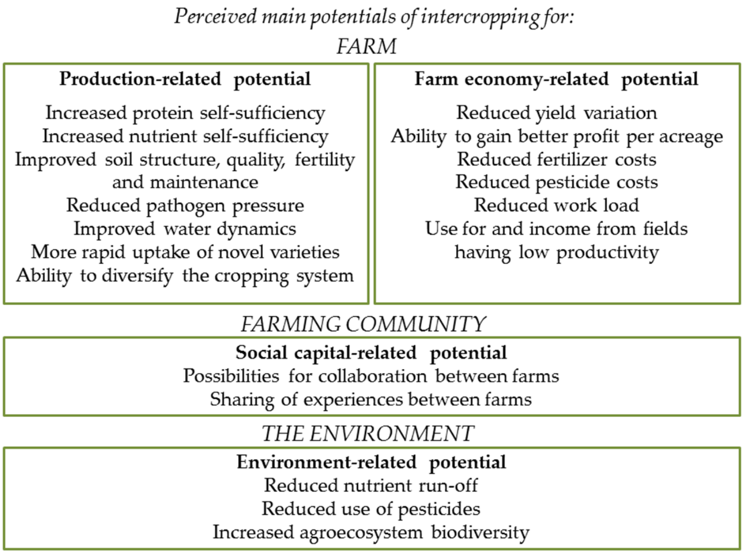

Figure 1. The main recognized potentials of using intercropping for the farm, farm community and the environment based on the actor workshop.

As perceived challenges for the use of intercropping, numerous challenges related to production, markets and policy, and knowledge gaps were identified (Figure 2). More demanding crop management and increasing workload for separating seeds for grain use were regarded as the likely challenges in the use of mixed intercropping. Support for the adoption of intercropping is also required through better knowledge on the optimal mixtures for specific production goals and local conditions and the suitability to markets and policy.

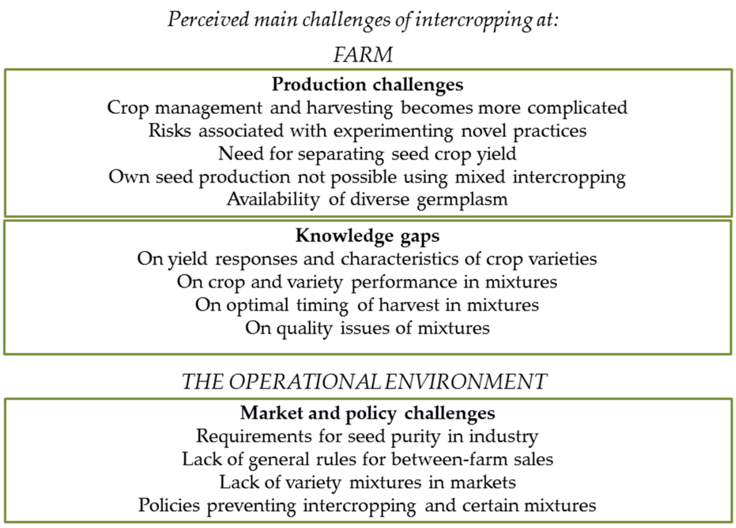

Figure 2. The main recognized challenges for using intercropping at the farm and the operational environment based on the actor workshop.

3.2. Designing Optimal Intercropping: The Most Promising Intercrops and Traits to Use in Finland

For the most promising intercrops to use in Finland, the participants listed crop species with the ability to biologically fix nitrogen (legumes), especially pea (*Pisum sativum* L.), faba bean (*Vicia faba* L.) and clovers (*Trifolium* sp.). Clovers were emphasized as possessing the additional benefit of improving soil structure. Green manure mixtures including legumes and deep-rooted species were also rated important. Cereal farms, in particular, were perceived to benefit from having green manure mixtures and undersown crops to diversify their crop rotations.

Other promising intercrops were deep-rooted crops that would improve soil structures such as lucerne (*Medicago sativa* L.), diverse undersown grass-legume mixtures to effectively and complementarily catch nutrients, autumn-sown crops such as winter turnip rape (*Brassica rapa* ssp. *oleifera* L.) and winter cereals to fully utilize the lengthening growing season and provide soil cover year-round, and special crops with the potential for beneficial health effects on cattle such as herbs and chicory (*Cichorium intybus* L.).

The traits mentioned more generally as important for use in intercropping included the aforementioned symbiotic nitrogen fixation, a deep-root profile to improve the soil structure, resistance to plant pathogens and novel crops with good market value. The workshop participants recognized also the potential of mixtures to buffer the yield from variations in soil properties (e.g., white clover in mixtures fills compacted soil patches well). In selecting the intercrops, the use of yield (whether for food, feed or green manure) as well as the soil type were found to largely determine the optimal combinations of genotypes to mix. The whole chain from field production to markets must also be considered when selecting the intercrops. It was discussed that the goals guiding the selection of intercrops vary by local conditions and field plot in annual versus perennial set-ups and that they are impacted by farm technical resources, multi-year planning such as crop rotations and farm development goals; case-by-case designs and learning-by-experimenting intercropping were emphasized.

3.3. Advancing the Uptake of Intercropping

Intercropping was perceived to demand courage from farmers to consider sowing multicrops instead of traditional monocultures and to allow more agroecosystem diversity, especially for the most common monocultures: cereal cropping. Forage mixtures and green manures are easy to adopt, and it was discussed that farmers have a high interest in experimenting with novel genotypes and mixture combinations. The selection of an available germplasm, breeding for good intercrop performance and the availability of seeds were found to be important in allowing experimentation with more diverse mixtures in mixed intercropping at farms. Undersown crops and green manure are easy to add to the crop rotations of specialized cereal farms, and their benefits for the soil structure and environment further supports their use. In addition, using intercropping to diversify might offer novel forms of collaboration between plant production and livestock farms and provide novel opportunities to produce feedstock for bioenergy use.

More farm-scale research on the different intercrop types, temporal set-ups and intercrop mixtures regarding their benefits or constraints in practice, as well as the sharing of farmer experiences, were believed to be important for advancing the adoption of the method more broadly. The intercropped mixed seed yields would need to have equal acceptance as monocropped yields by the industry (e.g., ability to sort different-sized seeds mechanically) to ensure the economic feasibility of developing the method for industrial crops. Alternatively, technical solutions such as using strip intercropping might help solve these challenges. For between-farm feed markets, the method was regarded as already having good potential.

Opinions were raised that the policies that regulate seed mixtures should be supportive for their use in various forms and allow seed suppliers to market not only crop mixtures but also varietal mixtures. The difficulty of enabling regulatory authorities to control for seed origin when using mixtures was raised. Furthermore, the inability of farmers to use their own seed for next year’s sowing when using mixed intercropping because the environmental conditions always shape the ratios of species in the final yield was discussed as potentially restricting the use of the method. It was concluded in the discussions that policies can be changed and regulations developed. Imperatively, agricultural policies should not limit but rather support the use of methods that have demonstrated benefits for the environment and climate change preparation.

4. Discussion

4.1. The Potential of Intercropping in Facing Climate Change

The recognized potentials of intercropping, albeit acknowledged to depend on the intercrops and the type of intercropping used, including enhanced yield security, soil conservation, regulation of water dynamics, buffering from pathogens, increased nutrient and protein self-sufficiency, and the reduced use of fossil energy-based external inputs, relate to addressing many climate change-related challenges for northern field cropping. Thus, intercropping can be regarded as both a targeted adaptive strategy of a farm, a potential climate-smart practice to be developed locally and context-specifically, and a means for enhancing farm adaptive capacity.

Of the recognized potentials, yield stability (low variation in yield) has been found to be higher in diverse stands of plant species, both in natural ecosystems [14] and in agroecosystems (reviewed by e.g., [39]). In the face of climate change, the higher incidence of weather extremes and changes in the amount and timing of precipitation are likely to induce even more variation in yields between years [26]. Because the yield responses to climate and weather differ among Finnish field crop species and varieties [25,40,41], securing a yield via intercropping might serve as a safeguarding strategy towards increasing uncertainty. By combining crops and varieties that possess differing growth rhythms, sensitivity and compensational abilities, a farmer might have a better chance of obtaining a sufficient yield despite meeting varying challenges related to climate, weather or growth resources.

Maintaining and improving soil quality and fertility via intercropping was regarded as an important potential of intercropping in our workshop. Soil is a central resource of farms, and it relates to both climate change mitigation and adaptation actions. Earlier studies have reported how diverse and prolonged soil cover and shade can protect soil from weather extremes such as heavy rain or prolonged drought [42]. Evaporation (water escaping into the air from bare soil) can be lower, and water use efficiency (water uptaken and transpired by the more dense canopy) can be higher with intercropping [43,44]. Field water dynamics, including water use efficiency, runoff and excess water, are increasingly important when considering water budgets and yield under climate change. In intercropping, plants with differing root structures can take up water from varying depths, and adding deep-rooted or drought-resistant crop genotypes can reduce the between-crop competition for scarce water [11]. Intercropping can induce root growth into deeper soil layers, as reported for, e.g., faba bean intercropped with wheat [45]. Increasing species diversity (a 16-species mixture) was also found to increase the deep-root (roots below 30 cm) biomass seven-fold compared with monoculture plots [46]. The extensive root biomass sequesters more carbon in the soil in carbon-depleted soils, especially in the deeper layers [47]. The increased vegetation cover and reduced tillage, as potentiated by relay intercropping, can also impact greenhouse gas emissions during winter-time melting and freezing cycles [48].

Reduced pathogen and insect pest infestation levels have been reported in several crop and variety mixtures; while, cases with no effects demonstrated by intercropping also exist [13,49]. The use of mixtures to limit pathogens was raised as one of the most important potentials for intercropping in the workshop, potentially reflecting the central importance of cereal diseases for yield quality in Finland. Case-specific impacts from diversification accrue due to the varying biology and host range of the various pathogens. For instance, soil-borne pathogenic diseases were reduced in 30 out of 36 studies comparing mixed cropping with sole cropping, and the severity of splash-dispersed diseases was reduced by intercropping in 10 out of 15 studies reviewed in [49]. By combining resistant and susceptible rice varieties in China, fungicide applications against rice blast were no longer needed [50], encouraging the testing of variety mixtures as well for pathogen control. The mechanisms operating to limit biotic stressors are not well known, which further complicates the assessment of the effectiveness of intercropping in pest control; e.g., some specialist herbivore pests use host-plant cues to orienting to a host, and a more diverse canopy can interfere with their ability to locate hosts, whereas generalist feeders might benefit from a more diverse host range [13]. The dilution of hosts can also directly limit the spread of pests and pathogens in the canopy [13,49]. Additionally, weed problems are often reduced in intercrop canopies via added crop density and soil cover time, increased competition for growth resources and allelopathy [51].

Legumes are the most often studied crops in intercropping [12,39]. They fix atmospheric nitrogen (N_2) symbiotically and thus reduce the need for nitrogen fertilizers, which was rated in our workshop as one of the most important production- and economy-related potentials for farms to benefit from intercropping. Legumes also provide protein, and their use supports the protein self-sufficiency of farms. Legume cropping is also beneficial for the mitigation of greenhouse gases because the energy input needed for manufacturing chemical fertilizers is conserved [12]. However, the legume-fixed nitrogen should be ensured to be used by the crops, e.g., via grass-legume intercropping rather than adding to nitrogen runoff and greater N_2O emissions [52,53]. It is known that legumes benefit from intercropping with cereals due to reduced lodging while the legume intercrop can support cereal yield and protein quality by laying reduced competition for nitrogen [39] and may enhance phosphorus uptake in phosphorus-deficient soils [16]. Legumes as a living mulch also suit well to undersowing with winter crops; e.g., a legume mixture reduced weeds by 20%–75% in winter oilseed rape [54]. Thus, the workshop findings on multiple potentials offered by legumes as intercrops, including both annual grain legumes and perennial species such as clovers and lucerne with their soil-supporting root systems, corroborates earlier studies on the multifaceted role of legumes in climate-smart agriculture [12].

The economic potentials recognized for using intercropping related to increasing the profit per acreage and reducing input costs. The production efficiency per acreage and the economic profitability of intercropping have been extensively characterized by calculating land equivalent ratios (ratio of acreages needed in monocropping to produce the corresponding total yields gained in intercropping) and monetary indices [11]. Both improved land use efficiency and economic returns have often been reported to indicate the improved use of growth resources and the use of reduced inputs in intercropping (reviewed in [39]). Thus, the method can offer farmers' gains in both productivity and economics when planned well.

The most important perceived environmental benefits of intercropping related to the reduced use of agrochemical inputs and the catch crops preventing nutrient run-off and soil erosion. Intercropped undersown catch crops can be added with little yield penalty for the main crop [55]. The additional benefit of intercropping in catch cropping is complementarity, e.g., combining grasses that take up excess nutrients and legumes that offer biological nitrogen for growth. The value of adding diversity into the agroecosystem itself was also mentioned as important. This relates to valuing cultural ecosystem services as well as supporting beneficial arthropods such as natural enemies of herbivores conferring biological control and pollinators, which links also to the conservation of natural biota and how it can be supported by agroecosystems [9]. Such diversification by intercropping can positively impact the landscape and regional scale adaptation to climate change [7].

4.2. Strengthening the Adaptive Capacity of Farmers: The Role of Intercropping

Farmers employ various adaptations in their everyday life as part of their decision-making on how to organize farm practices and pursue farm development. Climate change adaptations typically relate to investing on technological innovations (irrigation, bioenergy), diversification strategies, altered management (i.e., selection of varieties and crops to grow, timing of sowing, fertilization) and the building of social networks (i.e., field crop farm and animal husbandry farms collaborating, shared machinery) [29]. The ability of a farmer to employ certain adaptations beforehand to reduce adverse impacts by climate change relates to the general adaptive capacity of the farm: the ability to plan and use adaptations proactively [28]. General adaptive capacity has been characterized by, e.g., economic resources, technological options, information, institutions, equity, human and social capital and risk aversion ability [56]. Based on our workshop findings on the potentials recognized in intercropping, the method can be used as a means to enhance the adaptive capacity of farms more generally. Thus, it represents a way of employing physical resources and human and social capital (knowledge, novel collaborations) to face differential challenges. However, empirical assessments are needed to assess the relationship between specific intercropping practices and farm performance that mirrors farm adaptive capacity over time in practice.

Designing intercropping is a knowledge-intensive process that combines scientific and practical expertise [57]. As a first step, the knowledge on the potential of the method among farmers, advisers and the whole food production chain needs to be improved. Arbuckle et al. [20] found that the adoption of cover cropping by farmers in Iowa was related to the gained experience of their benefits, the presence of facilitative educational and technological infrastructure, and the development of risk abatement strategies for intercrop trials. More farm-scale research, as suggested also by our workshop, should be conducted to assess the pros and cons of the method in practice and provide more detailed instructions on how to employ, leverage and develop the method. Many possibilities exist for practicing intercropping such that guidelines and better knowledge on how to select the best type of intercropping (row, strip, mixed intercropping), the species or variety genotypes to combine, adjusting the timing of sowing/planting and management and considering local and production-specific goals are obviously needed. Accessibility, i.e., the availability of the method to farmers is good because relatively little additional economic investments are typically needed, and in contrast, economic costs can be reduced via reduced input use [11]. As revealed by the challenges recognized for adoption of the method more broadly, the usability of the different spatiotemporal types of intercropping depends on the technological and educational resources of the farm, agricultural policies, the germplasm available by breeding and markets.

4.3. Advancing Intercropping

The key traits mentioned as important in intercropping were biological nitrogen fixation, improvement of the soil structure by deep root systems, pathogen resistance and the crop properties related to health benefits in feed use. Both the quantity and quality (palatability) are imperative for producing feed, and optimally selected mixtures could improve both. Better knowledge on species and varieties in terms of optimal harvesting time, quality and performance in mixtures was raised as important for designing optimal forage mixtures. This would allow the most benefit to be gained: good quality multiple yields from the same field with a single sowing. Mixing species or varieties that possess differing developmental cycles could help fully leverage the growing season, which is particularly important in northern locations such as Finland. Variability exists in the sensitivity of crop varieties to different agroclimatic factors as reported earlier for barley varieties [40] and the forage species and varieties [41] used in Finland. Such information could be utilized more when planning intercrop mixtures to secure yields from winter damage and excess precipitation, which are important in Finnish conditions.

Breeding for optimal performance in mixtures, "adapting the crops to grow well together", was an innovative suggestion made at the workshop. To our knowledge, intercropping performance has not been a central criterion for breeding to date. However, especially concerning the traits that are scarcely addressed in traditional breeding, breeding for optimal mixtures might provide alternative ways for advancement. Seed suppliers likely have an interest in the experimental mixing of the existing genotypes and the search for novel markets by diversifying their supply via more tailored products in a faster pace this way. However, for northern latitudes, the selection of crop genotypes to use is more restricted than for more southern regions, which partly reduces the combinations to be tested. The available germplasm obviously determines much of the potential to be gained by intercropping.

Farmer-initiated innovations on optimal intercrop mixtures depend on having a wide trait and variety base for trials. Research and breeding are in a key position to advance these innovations.

The dominant conventional way of producing certain crops such as cereals as monocrops and the added complexity in management practices when all intercrops must be considered were found to restrict the wider uptake and development of intercropping in practice. In addition, undeveloped markets for mixture yields can create barriers. Seed availability and the possibility of separating seeds at mills are also central issues. Similar challenges have been reported by Anil et al. [58] and Steen Jensen et al. in organic cropping [59]. This further emphasizes the importance of joint innovation by farmers, researchers, industry and policymakers to advance intercropping.

4.4. Methodological Considerations

The introduction on intercropping in the workshop included information on the reported impacts in research and farmer experiences, and the possibility of this impacting the perceptions gathered should be acknowledged. However, not all topics raised in the introductions were listed in the workshop discussions, e.g., reducing insect pest pressure was not highlighted as a main potential by the actors themselves (whereas pathogens were), which reveals the active reflection of individual opinions and experiences. In addition, novel potential crops for intercropping such as lucerne and chicory were recognized by the actors. The notions raised reflect the issues considered most important or, alternatively, those that the actors have experienced themselves. Widening the study to a survey for a larger sample of Finnish farmers and a quantitative analysis on opinions might help reveal more general patterns and innovative intercrop solutions. However, because the use of intercropping is mostly restricted to forage crops, undersown crops and cereal mixtures in Finland, such a survey might not yield much data for advancing into novel forms of intercropping. Thus, the workshop was optimal for allowing dialogue on opinions and ideas and reaching more unanimity on the potential benefits and barriers analysed from a wide perspective. The sharing of experiences and discussion among actors with different backgrounds, i.e., farmers, advisors, officers and researchers, all included as workshop participants, further facilitated the development of a systemic view on the potential of intercropping for future agrifood systems.

5. Conclusions

We conclude that intercropping, with varying spatiotemporal arrangements, management options and genotype combinations, was recognized to have potential as an adaptation strategy for addressing climate change by strengthening farm adaptive capacity and developing multi-benefit climate-smart solutions for agriculture. Future research should empirically test and compare the gains to be achieved in practice for the recognized potentials. Intercropping design should target the most potent intercrop arrangements that are found locally and address the main goals set. Both farmer and advisor experiences and ecological and agronomic research knowledge are needed to gain and spread knowledge on the optimal mixtures and traits, allow technical development and economic optimization, and encourage policy and market support. Our study serves to raise awareness on the potential of intercropping for addressing climate change-induced cropping challenges in northern agriculture.

Acknowledgments: We gratefully thank the workshop participants for their valuable insights and contributions. Data collection was enabled by funding from the European Union and Rural Development Programme for Mainland Finland (Climate change and countryside (ILMASE) project) and from the Finnish Ministry of Agriculture and Forestry (Intercropping and variety mixtures (INTERCROP) project). The finalization of the study was supported by strategic funds from the Natural Resources Institute Finland (formerly MTT Agrifood Research Finland) and the Academy of Finland funding for SJH (decisions no. 257965 and 292783).

Author Contributions: All authors contributed to the design of the study and participated in collecting the data at the workshop; R.S. and S.J.H. gathered the data for analysis; and S.J.H. analysed the data. All authors took part in interpreting the data. S.J.H. wrote the paper with the support from all co-authors.

Conflicts of Interest: The authors declare no conflict of interest. The funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. FAOSTAT. Agri-Environmental Indicators. Agricultural Area (% of land area), 2011, the World. Available online: http://faostat3.fao.org/home/E (accessed on 19 March 2016).
2. Smith, P.; Martino, D.; Cai, Z.; Gwary, D.; Janzen, H.; Kumar, P.; McCarl, B.; Ogle, S.; O'Mara, F.; Rice, C.; et al. Greenhouse gas mitigation in agriculture. *Phil. Trans. R. Soc. B* **2008**, *363*, 789–813. [CrossRef] [PubMed]
3. Howden, S.M.; Soussana, J.F.; Tubiello, F.N.; Chhetri, N.; Dunlop, M.; Meinke, H. Adapting agriculture to climate change. *Proc. Natl. Acad. Sci.* **2007**, *104*, 19691–19696. [CrossRef] [PubMed]
4. Garnett, T.; Appleby, M.C.; Balmford, A.; Bateman, I.J.; Benton, T.G.; Bloomer, P.; Burlingame, B.; Dawkins, M.; Dolan, L.; Fraser, D.; et al. Sustainable intensification in agriculture: Premises and policies. *Science* **2013**, *341*, 33–34. [CrossRef] [PubMed]
5. Smith, P.; Olesen, J.E. Synergies between mitigation of, and adaptation to, climate change in agriculture. *J. Agric. Sci.* **2010**, *148*, 543–552. [CrossRef]
6. Food and Agriculture Organization of the United Nations. *Climate-Smart Agriculture Sourcebook*; 2013; p. 570. Available online: http://www.fao.org/docrep/018/i3325e/i3325e.pdf (accessed on 20 March 2016).
7. Campbell, B.M.; Thornton, P.; Zougmoré, R.; van Asten, P.; Lipper, L. Sustainable intensification: What is its role in climate smart agriculture? *Curr. Opin. Environ. Sustain.* **2014**, *8*, 39–43. [CrossRef]
8. Cong, W.F.; Hoffland, E.; Li, L.; Six, J.; Sun, J.H.; Bao, X.G.; Zhang, F.S.; Van der Werf, W. Intercropping enhances soil carbon and nitrogen. *Glob. Chang. Biol.* **2015**, *21*, 1715–1726. [CrossRef] [PubMed]
9. Tittonell, P. Ecological intensification of agriculture—Sustainable by nature. *Curr. Opin. Environ. Sustain.* **2014**, *8*, 53–61. [CrossRef]
10. Costanzo, A.; Bàrberi, P. Functional agrobiodiversity and agroecosystem services in sustainable wheat production. A review. *Agron. Sustain. Dev.* **2014**, *34*, 327–348. [CrossRef]
11. Vandermeer, J. *The Ecology of Intercropping*, 1st ed.; Cambridge University Press: Cambridge, UK, 1992; p. 237.
12. Jensen, E.S.; Peoples, M.B.; Boddey, R.M.; Gresshoff, P.M.; Hauggaard-Nielsen, H.; Alves, B.J.R.; Morrison, M.J. Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. A review. *Agron. Sustain. Dev.* **2012**, *32*, 329–364. [CrossRef]
13. Ratnadass, A.; Fernandes, P.; Avelino, J.; Habib, R. Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: A review. *Agron. Sustain. Dev.* **2012**, *32*, 273–303. [CrossRef]
14. Tilman, D.; Reich, P.B.; Knops, J.M.H. Biodiversity and ecosystem stability in a decade-long grassland experiment. *Nature* **2006**, *441*, 629–632. [CrossRef] [PubMed]
15. Ghaley, B.B.; Hauggaard-Nielsen, H.; Hogh-Jensen, H.; Jensen, E.S. Intercropping of wheat and pea as influenced by nitrogen fertilization. *Nutr. Cycl. Agroecosys.* **2005**, *73*, 201–212. [CrossRef]
16. Li, L.; Li, S.M.; Sun, J.H.; Zhou, L.L.; Bao, X.G.; Zhang, H.G.; Zhang, F.S. Diversity enhances agricultural productivity via rhizosphere phosphorus facilitation on phosphorus-deficient soils. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 11192–11196. [CrossRef] [PubMed]
17. Kontturi, M.; Laine, A.; Niskanen, M.; Hurme, T.; Hyövelä, M.; Peltonen-Sainio, P. Pea-oat intercrops to sustain lodging resistance and yield formation in northern European conditions. *Acta Agric. Scand. Sect. B Soil Plant Sci.* **2011**, *61*, 612–621. [CrossRef]
18. Hauggaard-Nielsen, H.; Johansen, A.; Sustmann Carter, M.; Ambus, P.; Steen Jensen, E. Annual maize and perennial grass-clover strip cropping for increased resource use efficiency and productivity using organic farming practice as a model. *Eur. J. Agron.* **2013**, *47*, 55–64. [CrossRef]
19. Creissen, H.E.; Jorgensen, T.H.; Brown, J.K.M. Stabilization of yield in plant genotype mixtures through compensation rather than complementation. *Ann. Bot.* **2013**, *112*, 1439–1447. [CrossRef] [PubMed]
20. Arbuckle, J.G., Jr.; Roesch-McNally, G. Cover crop adoption in Iowa: The role of perceived practice characteristics. *J. Soil Water Conserv.* **2015**, *70*, 418–429. [CrossRef]
21. Ruosteenoja, K.; Räisänen, J.; Venäläinen, A.; Kämäräinen, M. Projections for the duration and degree days of the thermal growing season in Europe derived from CMIP5 model output. *Int. J. Climatol.* **2016**, *36*, 3039–3055. [CrossRef]

22. Jylhä, K.; Fronzek, S.; Tuomenvirta, H.; Carter, T.R.; Ruosteenoja, K. Changes in frost, snow and Baltic sea ice by the end of the twenty-first century based on climate model projections for Europe. *Clim. Chang.* **2008**, *86*, 441–462. [CrossRef]
23. Ylhäisi, J.S.; Tietäväinen, H.; Peltonen-Sainio, P.; Venäläinen, A.; Eklund, J.; Räisänen, J.; Jylhä, K. Growing season precipitation in Finland under recent and projected climate. *Nat. Hazards Earth Syst. Sci.* **2010**, *10*, 1563–1574. [CrossRef]
24. Jylhä, K.; Tuomenvirta, H.; Ruosteenoja, K. Climate change projections for Finland during the 21st century. *Boreal Environ. Res.* **2004**, *9*, 127–152.
25. Peltonen-Sainio, P.; Venäläinen, A.; Mäkelä, H.M.; Pirinen, P.; Laapas, M.; Jauhiainen, L.; Kaseva, J.; Ojanen, H.; Korhonen, P.; Huusela-Veistola, E.; et al. Harmfulness of weather events and the adaptive capacity of farmers at high latitudes of Europe. *Clim. Res.* **2016**. [CrossRef]
26. Ray, D.K.; Gerber, J.S.; MacDonald, G.K.; West, P.C. Climate variation explains a third of global crop yield variability. *Nat. Commun.* **2015**, *6*, 5989. [CrossRef] [PubMed]
27. Hakala, K.; Hannukkala, A.O.; Huusela-Veistola, E.; Jalli, M.; Peltonen-Sainio, P. Pests and diseases in a changing climate: A major challenge for Finnish crop production. *Agric. Food Sci.* **2011**, *20*, 3–14. [CrossRef]
28. Smit, B.; Wandel, J. Adaptation, adaptive capacity and vulnerability. *Glob. Environ. Chang.* **2006**, *16*, 282–292. [CrossRef]
29. Darnhofer, I.; Bellon, S.; Dedieu, P.; Milestad, R. Adaptiveness to enhance the sustainability of farming systems. A review. *Agron. Sustain. Dev.* **2010**, *30*, 545–555. [CrossRef]
30. Williams, C.; Fenton, A.; Huq, S. Knowledge and adaptive capacity. *Nat. Clim. Chang.* **2015**, *5*, 82–83. [CrossRef]
31. Patt, A.; Suarez, P.; Gwata, C. Effects of seasonal climate forecasts and participatory workshops among subsistence farmers in Zimbabwe. *Proc. Natl. Acad. Sci. USA* **2005**, *102*, 12623–12628. [CrossRef] [PubMed]
32. Caron, P.; Biénabe, E.; Hainzelin, E. Making transition towards ecological intensification of agriculture a reality: The gaps in and the role of scientific knowledge. *Curr. Opin. Environ. Sustain.* **2014**, *8*, 44–52. [CrossRef]
33. Ensor, J.; Harvey, B. Social learning and climate change adaptation: Evidence for international development practice. *WIREs Clim. Chang.* **2015**, *6*, 509–522. [CrossRef]
34. Kantojärvi, P. *Fasilitointi luo Uutta. Menesty Ryhmän Vetäjänä*, 2nd ed.; Talentum: Helsinki, Finland, 2011; p. 280. (In Finnish)
35. Hogan, C. *Practical Facilitation: A Toolkit of Techniques*, 1st ed.; Kogan Page: London, UK; Sterling, VA, USA, 2003; pp. 265–273.
36. Auvine, B.; Densmore, B.; Extrom, M.; Poole, S.; Shanklin, M. *A Manual for Group Facilitators*; The Center for Conflict Resolution: Rutledge, GA, USA, 1977; pp. 39–40.
37. Kaner, S.; Lind, T.; Toldi, C.; Fisk, S.; Berger, D. *Facilitator's Guide to Participatory Decision-Making*, 2nd ed.; John Wiley & Sons, Inc.: San Francisco, CA, USA, 2007; pp. 106–107.
38. Jones, R.W. Learning and teaching in small groups: Characteristics, benefits, problems and approaches. *Anaesth. Intens. Care* **2007**, *35*, 587–592.
39. Bedoussac, L.; Journet, E.P.; Hauggaard-Nielsen, H.; Naudin, C.; Corre-Hellou, G.; Steen Jensen, E.; Prieur, L.; Justes, E. Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. *Agron. Sustain. Dev.* **2015**, *35*, 911–935. [CrossRef]
40. Hakala, K.; Jauhiainen, L.; Himanen, S.J.; Rötter, R.; Salo, T.; Kahiluoto, H. Sensitivity of barley varieties to weather in Finland. *J. Agric. Sci.* **2012**, *150*, 145–160. [CrossRef] [PubMed]
41. Mäkinen, H.; Kaseva, J.; Virkajärvi, P.; Kahiluoto, H. Managing resilience of forage crops to climate change through response diversity. *Field Crops Res.* **2015**, *183*, 23–30. [CrossRef]
42. Lin, B.B. Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture. *Agric. For. Meteorol.* **2007**, *144*, 85–94. [CrossRef]
43. Walker, S.; Ogindo, H.O. The water budget of rainfed maize and bean intercrop. *Phys. Chem. Earth* **2003**, *28*, 919–926. [CrossRef]
44. Fan, Z.; An, T.; Wu, K.; Zhou, F.; Zi, S.; Yang, Y.; Xue, G.; Wu, B. Effects of intercropping of maize and potato on sloping land on the water balance and surface runoff. *Agric. Water Manag.* **2016**, *166*, 9–16. [CrossRef]

45. Bargaz, A.; Isaac, M.E.; Jensen, E.S.; Carlsson, G. Intercropping of faba bean with wheat under low water availability promotes faba bean nodulation and root growth in deeper soil layers. *Procedia Environ. Sci.* **2015**, *29*, 111–112. [CrossRef]
46. Mueller, K.E.; Tilman, D.; Fornara, D.A.; Hobbie, S.E. Root depth distribution and the diversity-productivity relationship in a long-term grassland experiment. *Ecology* **2013**, *94*, 787–793. [CrossRef]
47. Kell, D.B. Large-scale sequestration of atmospheric carbon via plant roots in natural and agricultural ecosystems: Why and how. *Phil. Trans. R. Soc. B* **2012**, *367*, 1589–1597. [CrossRef] [PubMed]
48. Dörsch, P.; Palojärvi, A.; Mommertz, S. Overwinter greenhouse gas fluxes in two contrasting agricultural habitats. *Nutr. Cycl. Agroecosyst.* **2004**, *70*, 117–133. [CrossRef]
49. Hiddink, G.A.; Termorshuizen, A.J.; van Bruggen, A.H.C. Mixed cropping and suppression of soilborne diseases. In *Genetic Engineering, Biofertilisation, Soil Quality and Organic Farming*; Sustainable Agriculture Reviews 4; Lichtfouse, E., Ed.; Springer Science + Business Media: Dordrecht, The Netherlands, 2010; pp. 119–146.
50. Zhu, Y.; Chen, H.; Fan, J.; Wang, Y.; Li, Y.; Chen, J.; Fan, J.; Yang, S.; Hu, L.; Leungk, H.; et al. Genetic diversity and disease control in rice. *Nature* **2000**, *406*, 718–722. [CrossRef] [PubMed]
51. Liebman, M.; Dyck, E. Crop rotation and intercropping strategies for weed management. *Ecol. Appl.* **1993**, *3*, 92–122. [CrossRef]
52. Rochette, P.; Janzen, H.H. Towards a revised coefficient for estimating N_2O emissions from legumes. *Nutr. Cycl. Agroecosyst.* **2005**, *73*, 171–179. [CrossRef]
53. Hauggaard-Nielsen, H.; Lachouani, P.; Trydeman Knudsen, M.; Ambus, P.; Boelt, B.; Gislum, R. Productivity and carbon footprint of perennial grass–forage legume intercropping strategies with high or low nitrogen fertilizer input. *Sci. Total Environ.* **2016**, *541*, 1339–1347. [CrossRef] [PubMed]
54. Lorin, M.; Jeuffroy, M.H.; Butier, A.; Valantin-Morison, M. Undersowing winter oilseed rape with frost-sensitive legume living mulches to improve weed control. *Eur. J. Agron.* **2015**, *71*, 96–105. [CrossRef]
55. Valkama, E.; Lemola, R.; Känkänen, H.; Turtola, E. Meta-analysis of the effects of undersown catch crops on nitrogen leaching loss and grain yields in the Nordic countries. *Agric. Ecosyst. Environ.* **2015**, *203*, 93–101. [CrossRef]
56. Adger, W.N.; Brooks, N.; Bentham, G.; Agnew, M.; Eriksen, S. *New Indicators of Vulnerability and Adaptive Capacity*; Tyndall Centre for Climate Change Research: Norwich, UK, 2004; p. 122.
57. Malézieux, E. Designing cropping systems from nature. *Agron. Sustain. Dev.* **2012**, *32*, 15–29. [CrossRef]
58. Anil, L.; Park, J.; Phipps, R.H.; Miller, F.A. Temperate intercropping of cereals for forage: A review of the potential for growth and utilization with particular reference to the UK. *Grass Forage Sci.* **1998**, *53*, 301–317. [CrossRef]
59. Steen Jensen, E.; Bedoussac, L.; Carlsson, G.; Journet, E.P.; Justes, E.; Hauggaard-Nielsen, H. Enhancing yields in organic crop production by eco-functional intensification. *Sustain. Agric. Res.* **2015**, *4*, 42–50. [CrossRef]