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# Cultivar diversity has great potential to increase yield of feed barley

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**Abstract** This study shows an average yield increase of 415–1,338 kg ha<sup>-1</sup> per unit increase of the Shannon diversity index for feed barley cultivar use. There is a global quest to increase food production sustainably. Therefore, judicious farmer choices such as selection of crop cultivars are increasingly important. Cultivar diversity is limited and, as a consequence, corresponding crop yields are highly impacted by local weather variations and global climate change. Actually, there is little knowledge on the relationships between yields of regional crops and cultivar diversity, that is evenness and richness in cultivar use. Here, we hypothesized that higher cultivar diversity is related to higher regional yield. We also assumed that the diversity-yield relationship depends on weather during the growing season. Our data were based on farm yield surveys of feed and malting barley, *Hordeum vulgare* L.; spring wheat, *Triticum aestivum* L.; and spring turnip rape, *Brassica rapa* L. ssp. *oleifera*, from 1998 to 2009, representing about 4,500–5,500 farms annually. We modeled the relationships between regional yields and Shannon diversity indices in high-yielding (south-west) and low-yielding (central-east) regions of Finland using linear mixed models. Our results show that an increase of Shannon diversity index increases yield of feed barley. Feed barley had also the greatest cultivar diversity. In contrast, an

average yield decrease of 1,052 kg ha<sup>-1</sup> per unit increase in Shannon index was found for spring rape in 2006 and 2008. Our findings show that cultivar diversification has potential to raise mean regional yield of feed barley. Increasing cultivar diversity thus offers a novel, sustainability-favoring means to promote higher yields.

**Keywords** Crop cultivar · Diversity · Environmental responses · Regional yields · Yield security

## 1 Introduction

Increasing diversity of plant species and genotypes in cropping systems through crop rotation, intercropping, and conservation of biodiversity along field margins is known to promote broader ecological interaction networks (Brussaard et al. 2007; Jackson et al. 2007). Crop diversification is key to maintaining many ecosystem services: high diversity has been found to conserve soil and improve nutrient use (Brussaard et al. 2007), provide associational resistance to herbivores and enhance pest control by natural enemies (Glinwood et al. 2009), and reduce pathogen pressure (Zhu et al. 2000). Benefits for ecosystem productivity (Tilman et al. 2001; Smith et al. 2008) and sustainability (Lin 2011) from increased diversification have been reported widely. In addition, diversity makes up much of the ecosystem's stability against environmental disturbances (Elmqvist et al. 2003; Tilman et al. 2006). This relates to the potential of diversity to enhance system resilience: ability to maintain function and reorganize while facing external disturbance and change (Lin 2011). As global food and forage production needs to be increased sustainably, the potential of diversification of cropping systems to raise or secure crop yields needs to be better understood.

In practice, the number of crops grown on a farm is often limited by factors such as the local climate, technology and machinery availability, expertise, and economics. Crop

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diversification by employing intercropping may secure yield and increase total yield per unit area, but the area available for the main crop is reduced and cultivation more complicated (Letourneau et al. 2011). Using different cultivars rather than different crops to diversify cropping might thus represent a more feasible option, in a practical and economic sense, on farms. Cultivar blends have often been found to provide higher (Essah and Stoskopf 2002; Kiaer et al. 2009) and more stable (Helland and Holland 2001; Kiaer et al. 2009) yields than pure-line cultivars. Growing cultivar mixtures can, in some cases, reduce disease pressure (Mundt 2002) and pest damage (Glinwood et al. 2009). At the regional scale, more cultivars are in use than on individual farms. In addition, regional yields are produced under a wider range of environmental conditions than farm-based studies usually include. A novel approach to assessing diversity effects, regional analysis as used in our study, indicates how cultivar diversity, in terms of richness and evenness of cultivar use, could be applied to provide yield gains and security towards weather on larger spatial scales.

When considering the future of practicing sustainable agriculture, risk perception and awareness are of increasing importance since the global climate change is characterized by great uncertainty in terms of impacts on both spatial and temporal scales (Beniston et al. 2007). Already in the near future, traditional crop management and crop selection criteria will no longer suffice to cope with anticipated changes, but farmers need to adapt and plant breeding will face new challenges (Howden et al. 2007). Advancing climate change is expected to impact agriculture at northern latitudes directly via more frequent weather extremes, such as heat waves, heavy rains, and prolonged drought (Beniston et al. 2007), but also via extended thermal growing seasons that may lead to higher production potentials (Peltonen-Sainio et al. 2009). However, the role of genetic diversity and diverse cultivar use in enhancing robustness of agriculture towards climate change including the higher frequency of weather extremes, has been little studied to date. Insurance of crop yields via diversification might be underestimated.

The “insurance” hypothesis proposed by Yachi and Loreau (1999) that “many species provide greater guarantees that some will maintain functioning even if others fail” was tested here for crop cultivars at the regional level. Yachi and Loreau (1999) suggested that both buffering and performance-enhancing effects stem from diversity. Mean yield levels are a suitable indicator for assessing benefits of cultivar diversity at regional scale, since they correspond directly to performance. Insurance via diversification could take place at the farm level (Reidsma and Ewert 2008) and at higher spatial levels in support of farm, regional, and national yield security (Adger et al. 2007; Howden et al. 2007). Increased yield stability, i.e., lower variation in yields over a time series has often been one benefit of diversification, e.g., in cultivar

mixtures (Helland and Holland 2001). Using regional data to assess the relationship between cultivar diversity and yield stability is challenging, as diversity and its components change over time and farms employ a plethora of agronomic practices, which are also adapted according to environmental conditions each year. However, growing seasons with exceptional weather that challenge production might reveal yield insurance by regional cultivar diversification: diversification could be more strongly related to yield levels in such years. To the best of our knowledge, no previous studies exist on the potential gains in yields in relation to high cultivar diversity at a regional scale (see Jarvis et al. 2008 for a related perspective). If these were found to coincide, diversification of regional cultivar use could reduce regional vulnerability of crop production. If the potential of diversity to provide yield security were better understood, strategies for more resilient cropping in the future might be realized and co-benefit the environment, crop yields, and farm economy by improved risk management (Lin 2011).

Here, we assessed the relationship between regional cultivar diversity and yield for four important crops in Finland, feed and malting barley (*Hordeum vulgare* L.), spring wheat (*Triticum aestivum* L.), and spring turnip rape (*Brassica rapa* L. ssp. *oleifera*; Fig. 1). We hypothesized that cultivar diversity is positively related to regional yield and according to the insurance hypothesis: the relationship is strongest in years when the growing season is uncharacteristically long or short, or when the precipitation sum is exceptionally high or low compared with average regional values.

## 2 Materials and methods

### 2.1 Cultivar distribution and yield data

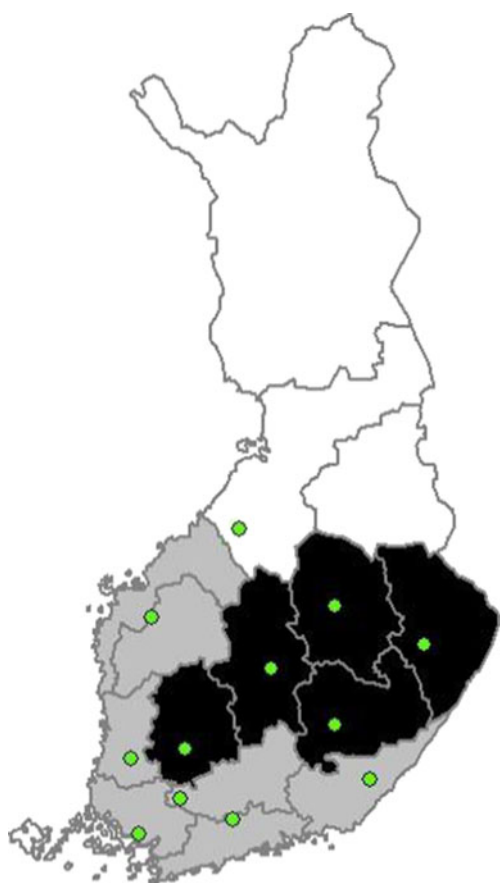
Cultivar lists and annual cultivated areas (1998–2009) per cultivar were obtained from TIKE (The Information Centre of the Ministry of Agriculture and Forestry, Finland) for all Finnish farms registered for the agricultural subsidy system for: feed and malting barley, spring turnip rape, and spring wheat. The crops were selected to include two important spring cereals grown in Finland, barley (feed barley cultivated on 377,900 ha and malting barley on 87,700 ha in 2011) and spring wheat (217,000 ha) plus an oilseed crop (spring rape 78,000 ha). Cultivated areas were classified on a regional basis (16 regions, shown in Fig. 2). Data on mean yields for these regions per crop and per annum were obtained from TIKE for the same time period. These regional yields were means calculated from yield data provided by farms that were selected to take part in TIKE’s annual yield surveys (ca. 4,500–5,500 farms per annum, one third of farms in the survey changing annually).

The northernmost and southernmost and eastern versus western regions of Finland differ considerably in terms of

**Fig. 1** Barley (*H. vulgare* L.; left photo: Tapio Tuomela/MTT's archive), spring wheat (*T. aestivum* L.; center, photo: Tapio Tuomela/MTT's archive), and turnip rape (*B. rapa* ssp. *oleifera* L.; right photo: Tero Sivula, Rodeo/MTT's archive)



climate and mean yields. Thus, the three northernmost regions have very limited possibilities for agriculture and there is no significant cultivation of spring wheat, spring rape, or malting barley there. The Åland islands also have a



**Fig. 2** Map of 16 administrative regions in Finland of which seven regions represent the south-west (*gray*) and five regions the central-east (*black*) regional groups of the study. The yield levels in the south-west group exceeded the national mean yield in most years for the crops studied, whereas mean yields in the central-east group were below the national average. *Dots* indicate representative weather stations that were used to provide growing season temperature and precipitation sums for the regions. The northernmost weather station was located slightly northwards of the borderline of the region it characterized (northernmost region of the south-west regional group), but the station was considered representative enough due to similar local climate

limited cultivated area and were excluded from our analysis. The remaining regions were placed into two regional groups: south-west and central-east (Fig. 2). The yield levels in the south-west group exceeded the national mean yield in most years for the crops studied, whereas mean yields in the central-east group were below the national average. Regional yields were not available for the central-east group for malting barley due to the small area cultivated (<160 ha), which prevented reliable calculation of regional mean yield in 11 cases: in 2000–2001, 2004, 2006–2009 for North Karelia (easternmost region in Fig. 2), 2006–2007 and 2009 for North Savo (northernmost region west of North Karelia in Fig. 2) and 2009 for South Savo (south of North Savo in Fig. 2). Annual growing season temperature sums (degree Celsius, base T+5 °C) and precipitation sums (millimeters) as medians per regional group are provided in Fig. 3. The values are based on weather station data from the Finnish Meteorological Institute for representative stations in each region (locations shown in Fig. 2).

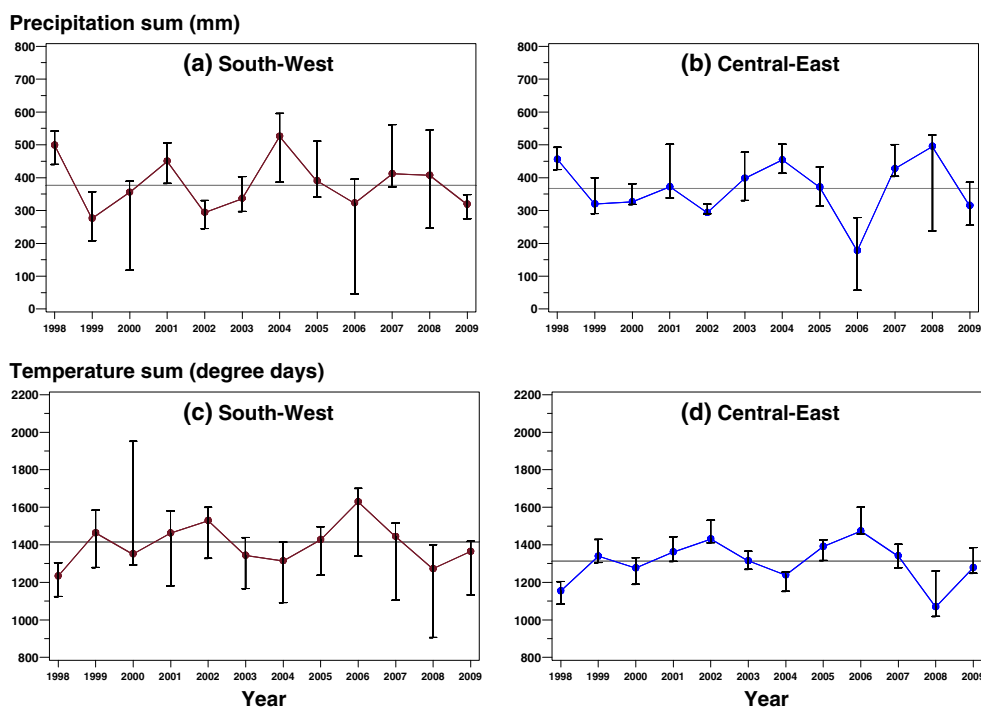
## 2.2 Describing cultivar diversity

The number of cultivars in use and their dominance (share of total cultivated area for top three cultivars) was calculated per crop, year, and region over 1998–2009. Cultivar diversity was described using the Shannon index (Shannon 1948), being the most commonly applied ecological diversity index and previously applied in economic and agricultural contexts as well (e.g., Reidsma and Ewert 2008). It takes into account both richness and evenness of specimen: here, an increase in Shannon index follows either from addition of unique cultivars or through greater cultivar evenness. Annual Shannon indices were calculated per crop and region using the following formula:

$$H' = - \sum_{i=1}^S \frac{n_i}{N} \ln \frac{n_i}{N}$$

where  $S$ =number of cultivars, i.e., cultivar richness,  $n_i$ =the cultivated area of individual cultivar, i.e., cultivar abundance, and  $N$ =total cultivated area. Each individual cultivar represented a unique class. In addition, one class was formed for cultivated areas lacking cultivar information.

**Fig. 3** Annual median, minimum and maximum values for growing season precipitation (a–b) and temperature (c–d) sums (sum of degree days above +5 °C) in the south-west and central-east regional groups (medians connected with lines). The years 1999, 2002, and 2006 were the driest and warmest, whereas 1998, 2004, and 2008 were the rainiest and coldest years. Growing season starts when average day temperature has been above +5 °C for over five consecutive days. The horizontal reference lines represent medians based on the medians for the study years 1998–2009 in each region



### 2.3 Statistical analyses

The data for the four crops were analyzed separately using linear mixed effects models (Milliken and Johnson 2002). The mean yields recorded in the same region over 1998–2009 tended to be intercorrelated, which was taken into account with the covariance structure of the within region errors. As the number of regions was small in comparison with the number of years, the data for 1998–2003 and 2004–2009 were modeled separately for each crop. The exception was malting barley, whose data were modeled in three parts (1998–2001, 2002–2005, and 2006–2009) due to missing values. The models were fitted using the restricted maximum likelihood estimation method.

Plots of regional mean yields against Shannon indices for each combination of the categories of crop, regional group, and year indicated that the relationship between mean yield and Shannon index was linear and could be modeled by a regression line. Similarly, a regression line was adequate to describe the relationship between mean yield and cultivated area. Consequently, the initial model, which was used in selecting an adequate covariance structure for the within region errors, had the following form:

$$\text{YIELD}_{ijk} = \alpha_{ik} + \beta_{ik}\text{SHANNON}_{ijk} + \gamma \text{AREA}_{ijk} + \tau_{j(i)} + e_{ijk}$$

where  $\text{YIELD}_{ijk}$ ,  $\text{SHANNON}_{ijk}$ , and  $\text{AREA}_{ijk}$  are the mean yield, Shannon index and cultivated area for region  $j$  within regional group  $i$  in year  $k$ , respectively. The parameter  $\alpha_{ik}$  is

the intercept and  $\beta_{ik}$  is the slope of the regression line that describes the relationship between mean yield and Shannon index for regional group  $i$  in year  $k$ , and the parameter  $\gamma$  is the slope for the cultivated area;  $r_{j(i)}$  denotes the random effect for region  $j$  within regional group  $i$ ;  $e_{ijk}$  is the random error associated with the measurement of year  $k$  from region  $j$  in regional group  $i$ . The random effects  $r_{j(i)}$  are assumed to be independent and Gaussian distributed with zero mean and constant variance. The effects  $r_{j(i)}$  are also distributed independently of the  $e_{ijk}$ . The “best” covariance structures for the errors  $e_{ijk}$  within a region were chosen through a comparison of different models by the likelihood ratio test and information criteria (Milliken and Johnson 2002). For feed barley, the “compound symmetry” (CS) covariance structure, in which all of the variances in different years are equal and similarly the pairwise covariances are equal to each other, appeared most appropriate for both year groups. For spring rape, the variability of mean yields among the regions was larger in the central-east than in the south-west group, and therefore the CS covariance model was adequate in 1998–2003 and 2004–2009, when estimated for the two regional groups separately. Also for spring wheat in 1998–2003, the CS covariance model fitted the data well but in 2004–2009, the “heterogeneous compound symmetry” (CSH) structure was needed to allow unequal variances of the errors in different years. For malting barley, the CSH structure was adequate in 2006–2009. In 1998–2001 and 2002–2005, the most appropriate covariance structures were CSH and CS, respectively, when estimated for the two regional groups separately.



After finding the “best” covariance model, the fixed effects part (the mean part) of the model  $\alpha_{ik} + \beta_{ik}\text{SHANNO}N_{ijk} + \gamma \text{AREA}_{ijk}$  was simplified. The model for the linear relationship between mean yield and Shannon index can also be written as

$$(\mu + R_i + Y_k + RY_{ik}) + (\theta + \rho_i + \nu_k + \delta_{ik}) \text{SHANNON}_{ijk}$$

where each intercept  $\alpha_{ik}$  and slope  $\beta_{ik}$  is expressed with an overall mean ( $\mu$  and  $\theta$ ), an effect due to regional group ( $R_i$  and  $\rho_i$ ), an effect due to year ( $Y_k$  and  $\nu_k$ ), and an effect due to the interaction between regional group and year ( $RY_{ik}$  and  $\delta_{ik}$ ). The dependence of the intercept and slope on regional group and/or year and the need to have cultivated area in the model was tested by eliminating terms from the model one at a time if they were not statistically significant, beginning with the term with the largest  $p$  value. In addition, the hierarchy principle was applied, which states that if a product term (e.g., a two-factor interaction) is retained in the model, then all lower-order components of that term (main effects of the factors) must be retained. The statistical significances of the model terms were determined using the  $F$  test, for which the denominator degrees of freedom were calculated according to Kenward and Roger (1997). The tests were type III tests in which each effect is adjusted for all other effects in the model. The multiple comparisons of the slopes and the deviations of the slopes from zero were tested using two-sided  $t$ -type tests. The analyses were performed with the MIXED procedure in version 9.2 of the SAS/STAT software (SAS Institute Inc. 2009). The adequacy of the models was diagnosed graphically. The normality assumption of the residuals was checked by using the box plot (Tukey 1977), and the constancy of the variance by plotting the residuals against the fitted values. In addition, the agreement of the final models with the data was checked by presenting the models together with the scatter diagrams of the data (e.g., Fig. 5). According to the plots, the final models fitted the data adequately.

### 3 Results and discussion

#### 3.1 Cultivar diversity over 1998–2009 in high-yielding (south-west) and low-yielding (central-east) regions of Finland

The number of cultivars in use on Finnish farms for all the crops included in this study increased over the 12-year period (Fig. 4a–d). There were more cultivars sown in the south-west regions than in the central-east regions for all crops. The underlying reason for this difference may be that the more favorable climate in the south-west regions supports usage of a higher number of cultivars, with also

breeding of novel varieties serving these dominant cereal cultivation areas best. Differences in farmer typology (adoption of novel cultivars) or the fact that cereal cultivation plays a smaller role in the central-east regions, where roughage-based dairy farming dominates, may also contribute to this result. Most cultivars existed for feed barley (Fig. 4a) and least for spring rape (Fig. 4b). The share of the three dominant cultivars showed a predominantly declining trend for all crops (Fig. 4e–h, ca. 10–30 % decrease over time), with the exception of spring wheat in the central-east region. For feed barley, the top three share and thus cultivar dominance was the lowest (Fig. 4e) of all crops and declined in the central-east region in particular. The largest differences in the development of cultivar dominance between the regions existed for spring rape (Fig. 4f, more dominance in south-west than central-east) and spring wheat (Fig. 4g, more dominance in central-east than south-west).

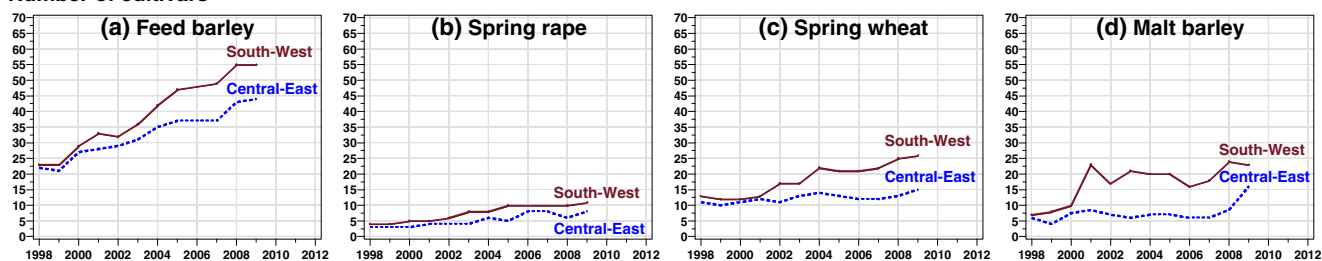
Shannon index mainly increased over time for all the crops studied (Fig. 4i–l), with the exception of the decreasing trend for spring wheat in the central-east region (Fig. 4k). Feed barley had the highest diversity index over the entire time period, and the difference between south-west and central-east regions remained relatively stable over time (Fig. 4i). The largest increase in Shannon index over time was for spring rape, for which the Shannon index was lowest in 1998 but doubled over the time period (Fig. 4j). The Shannon index increased over recent years in both regional groups for malting barley (Fig. 4l).

#### 3.2 Relationship between regional cultivar diversity and yield

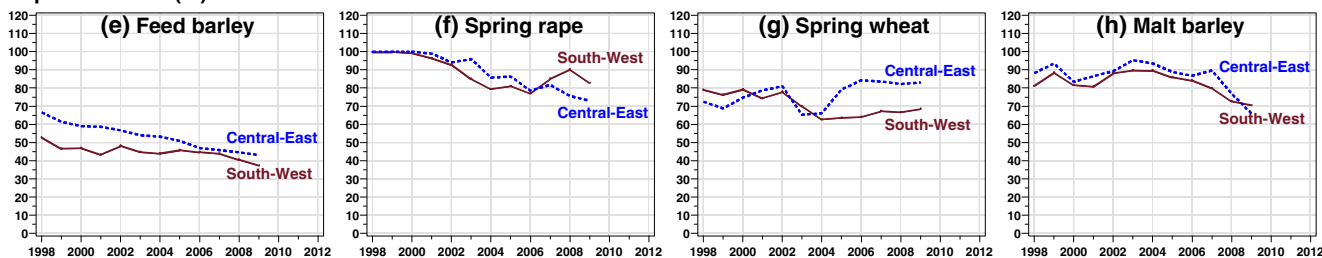
##### 3.2.1 Feed barley

Regional cultivar diversity, as measured using the Shannon index, was positively related to regional mean yield of feed barley in all years studied (Fig. 5). In 1998–2003, the slope of the regression line (the average rate of increase in mean yield per unit increase in Shannon index) depended neither on year nor on region after adjustment for cultivated area (Table 1). Consequently, a common slope model fitted the data adequately (slope=488, standard error (SE) of slope=124.4). Instead, the levels of the regression lines (intercepts) differed among years (Table 1) indicating differences in the average mean yields among years. For later years (2004–2009), the slopes of the regression lines depended on year (Table 1). Based on the slope estimates for the years and their multiple comparisons, the years were divided into two groups so that the slopes were considered homogeneous within groups and different between groups. The relationship between mean yield and cultivar diversity was strongest in 2004, 2005, 2007, and 2008 (common slope=1338, SE=291.1,  $p < 0.001$  for the hypothesis  $H_0$ : slope=0, Figs. 5

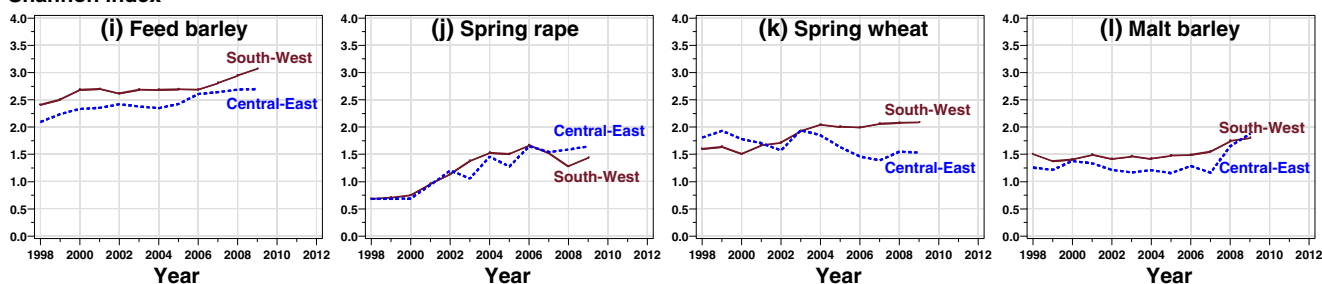
## Number of cultivars



## Top three share (%)



## Shannon index



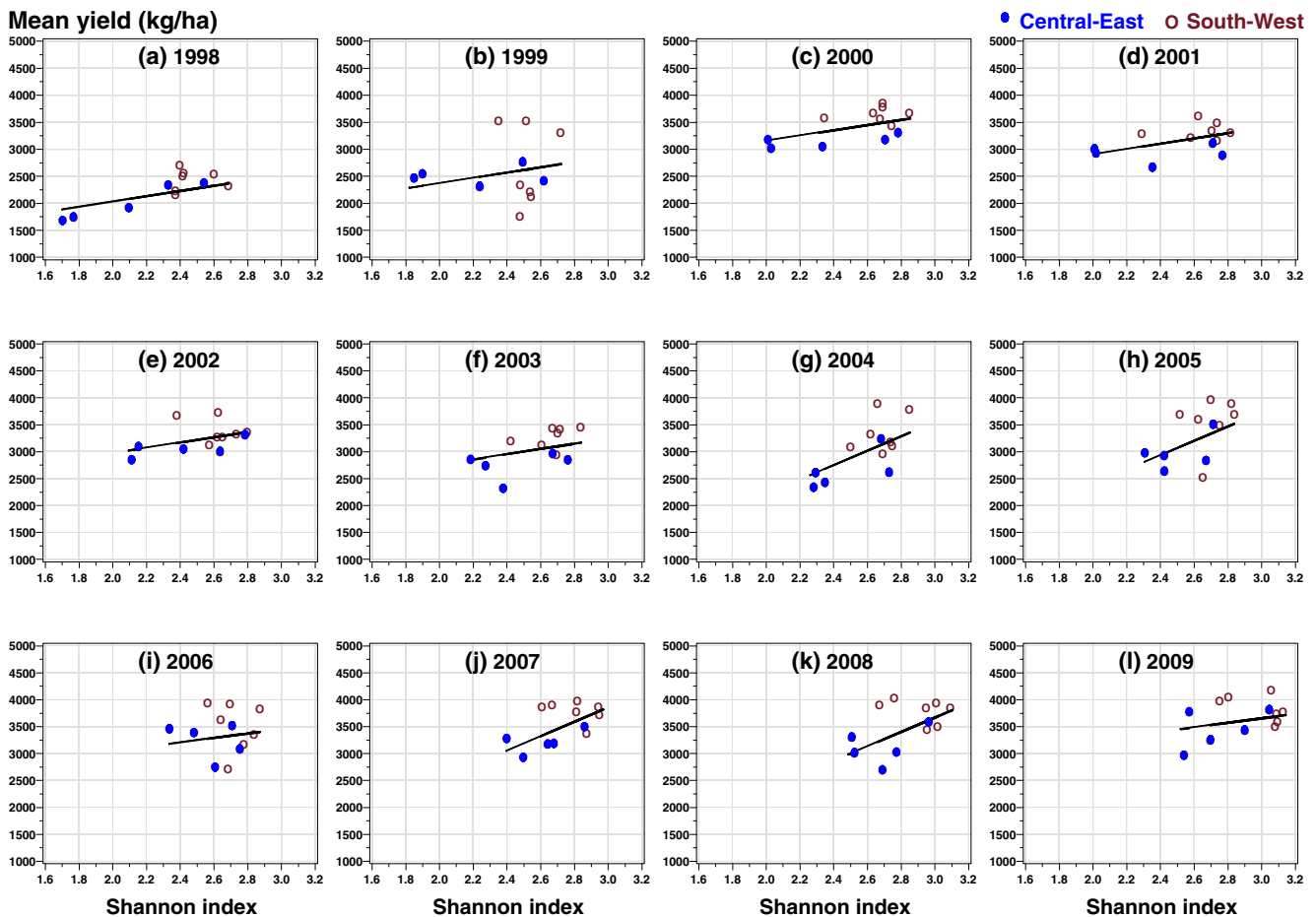
**Fig. 4** Crop-specific profiles of medians over 1998–2009 for the total number of cultivars in use (a–d), the percentage share of the top three cultivars (e–h), and Shannon index describing cultivar numbers and evenness of cultivation (i–l) in the south-west and central-east regional groups. Two to three times as many cultivars were sown in 2009 compared with 1998 for most crops (a–d). The share of the three dominant cultivars decreased by ca. 10–30 % (e–h) and Shannon index

mainly increased (i–l) over time for all the crops studied. The medians are based on seven regions in south-west and five regions in central-east, excluding malting barley in central-east in 2000, 2001, 2004 and 2008 (four regions), in 2006 and 2007 (three regions), and in 2009 (two regions). The percentage share of the top three cultivars=(cultivated area of the top three cultivars/total cultivated area in a region)×100

and 6a). The common slope for 2006 and 2009 was similar in magnitude to that for 1998–2003, but did not differ statistically significantly from zero due to a larger standard error (slope=415, SE=330.7,  $p=0.22$ ; Figs. 5 and 6a). There was no difference in the levels of the regression lines between the south-west and central-east regions, i.e., the differences in Shannon index and in cultivated area between the two regional groups accounted for the difference in mean yield between the groups (Fig. 5).

Feed barley was the crop with most cultivars available and the largest and spatially most widespread cultivation in Finland, and the positive relationship between diversity and yield was the clearest of all crops studied. Along with numerous cultivars, there is a large pool of feed barley genotypes representing a range in yield potential and weather responsiveness under Finnish conditions (Hakala et al. 2012). Thus, farmers are able to select well-adapted feed

barley cultivars for their locality and such selections can differ considerably among regions. Barley cultivation has a long history in Finland and both farmer knowhow and barley breeding are superior than for newer crops such as spring rape. Our results indicate that diversified use of barley cultivars in Finland is positively related to regional yields. The insurance hypothesis (Yachi and Loreau 1999) was best supported for feed barley in years with a high precipitation sum or experiencing heavy rain (years 2004, 2005 (heavy rains during growing season, although precipitation sum is only slightly above average), 2007, 2008 with a 1,338 kg ha<sup>-1</sup> yield increase on average per unit increase in Shannon index). In our previous study, yield response of Finnish barley cultivars to rainfall was mostly equal during early growth, but later in the season (3–7 weeks from sowing) a change from low (<39.4 mm) to moderate (39.5–63.3 mm) rainfall increased yield of most cultivars



**Fig. 5** Linear relationships between regional mean yield of feed barley and Shannon index describing cultivar diversity in the south-west and central-east regional groups in 1998–2009 (a–l). Regional cultivar diversity was positively related to regional mean yield of feed barley in all years studied (a–l). The relation was strongest in years with a

rainy growing season: 2004 (g), 2005 (h), 2007 (j), and 2008 (k). The differences in Shannon index and in cultivated area between the south-west and central-east regions accounted for the difference in mean yield between the two regional groups. The regression lines are determined for 25,000 ha cultivated area

(Hakala et al. 2012). Under high rainfall (>63.4 mm), variability in responsiveness of the barley cultivar pool increased. Alternatively, the benefit of high cultivar diversity on yield might result from the ability of a broad cultivar set to benefit optimally from higher precipitation in otherwise water-limited cultivation. Barley in particular has been found to be drought-sensitive during formation of yield potential, with little compensation for reduced grain number through increased grain size (Rajala et al. 2011).

### 3.2.2 Spring turnip rape

The slope of the regression line for spring rape depended on year both in 1998–2003 and in 2004–2009 (Table 1). In most years, the slope was small and there was no relationship between Shannon index and mean yield ( $p > 0.49$ , Fig. 6b). However, a positive relationship was detected in 1999 (slope=869, SE=277.4,  $p < 0.005$ ), whereas a negative association was recorded for 2006 and 2008 (common

slope=-1,052, SE=222.1,  $p < 0.001$ , Fig. 6b). A tendency towards a negative relationship was established for 2007 and 2009 (slope=-394, SE=246.4,  $p = 0.12$ , Fig. 6b). Mean yield did not vary between the two regional groups or with cultivated area after accounting for the effects in the final model (Table 1).

In 1999, higher cultivar diversity might have represented yield insurance from drought when two cultivars, Kulta and Valo, largely dominated spring rape cultivation in Finland (over 1998–2003). After 2004, a few additional cultivars, such as Tuli, Hohto, SW Petita, and Apollo, with the last two playing lead roles, have slowly contributed to diversification of cultivar use. As a whole, spring rape had the least number of cultivars available, also due to its short history of cultivation in Finland (extensive cultivation started only after 1976). In addition, an increase in cultivar number might not contribute much if the new cultivars becoming available resemble each other much and do not represent adequate diversity in their environmental responsiveness.



**Table 1** Crop-specific results for the fixed effects in the final mixed-effects models

Crop	Effect	<i>df</i>	<i>F</i>	<i>P</i>	<i>df</i>	<i>F</i>	<i>P</i>	<i>df</i>	<i>F</i>	<i>P</i>
		Years 1998–2003			Years 2004–2009					
Feed barley ( <i>n</i> =144)	Cultivated area	1, 10	23.07	<0.001	1, 9	33.15	<0.001			
	Year	5, 57	22.25	<0.001	5, 49	3.32	0.01			
	Shannon	1, 10	15.41	<0.005	1, 13	13.24	<0.005			
	Year×Shannon	–	–	–	5, 49	3.03	0.02			
Spring rape ( <i>n</i> =144)	Year	5, 37	1.82	0.13	5, 34	5.24	<0.005			
	Shannon	1, 22	0.66	0.43	1, 39	12.50	<0.005			
	Year×Shannon	5, 36	2.59	0.04	5, 34	3.99	0.01			
Spring wheat ( <i>n</i> =144)	Region group	1, 60	5.09	0.03	1, 37	0.83	0.37			
	Year	5, 55	22.45	<0.001	5, 18	0.98	0.45			
	Region group×year	–	–	–	5, 18	3.17	0.03			
	Shannon	1, 60	0.94	0.34	1, 37	1.46	0.23			
	Region group×Shannon	1, 61	8.59	<0.005	1, 37	0.37	0.54			
	Year×Shannon	–	–	–	5, 18	0.81	0.56			
	Region group×year×Shannon	–	–	–	5, 18	3.31	0.03			
			Years 1998–2001			Years 2002–2005			Years 2006–2009	
Malt barley ( <i>n</i> =133)	Year	3, 11	20.50	<0.001	3, 28	3.84	0.02	3, 15	4.36	0.02
	Region group	–	–	–	1, 10	4.63	0.06	1, 11	10.50	0.01
	Shannon	–	–	–	1, 15	6.20	0.02	–	–	–
	Year×Shannon	–	–	–	3, 28	4.66	0.01	–	–	–

The results describe the linear relationship between regional mean yield and Shannon index and the dependence of the relationship on regional group and/or year after adjustment for cultivated area (if needed)

*n* the number of observations, *df* degrees of freedom (numerator, denominator)

The negative relationship between cultivar diversity and yield that dominated over recent years might suggest that the genetic base they represent was not sufficient to create diversity-related positive effects on regional yields of spring rape. Our results might offer an explanation why yields of spring rape have remained low or declined in the 2000s in Finland (Peltonen-Sainio et al. 2007): low yields might reflect current narrow genetic base of the cultivar pool towards resisting environmental variation combined with the fact that only few cultivars have a high yield potential, at least in Finnish conditions. Efforts may be needed to breed for wider-scale environmental stability in spring rape cultivars suitable for northern regions.

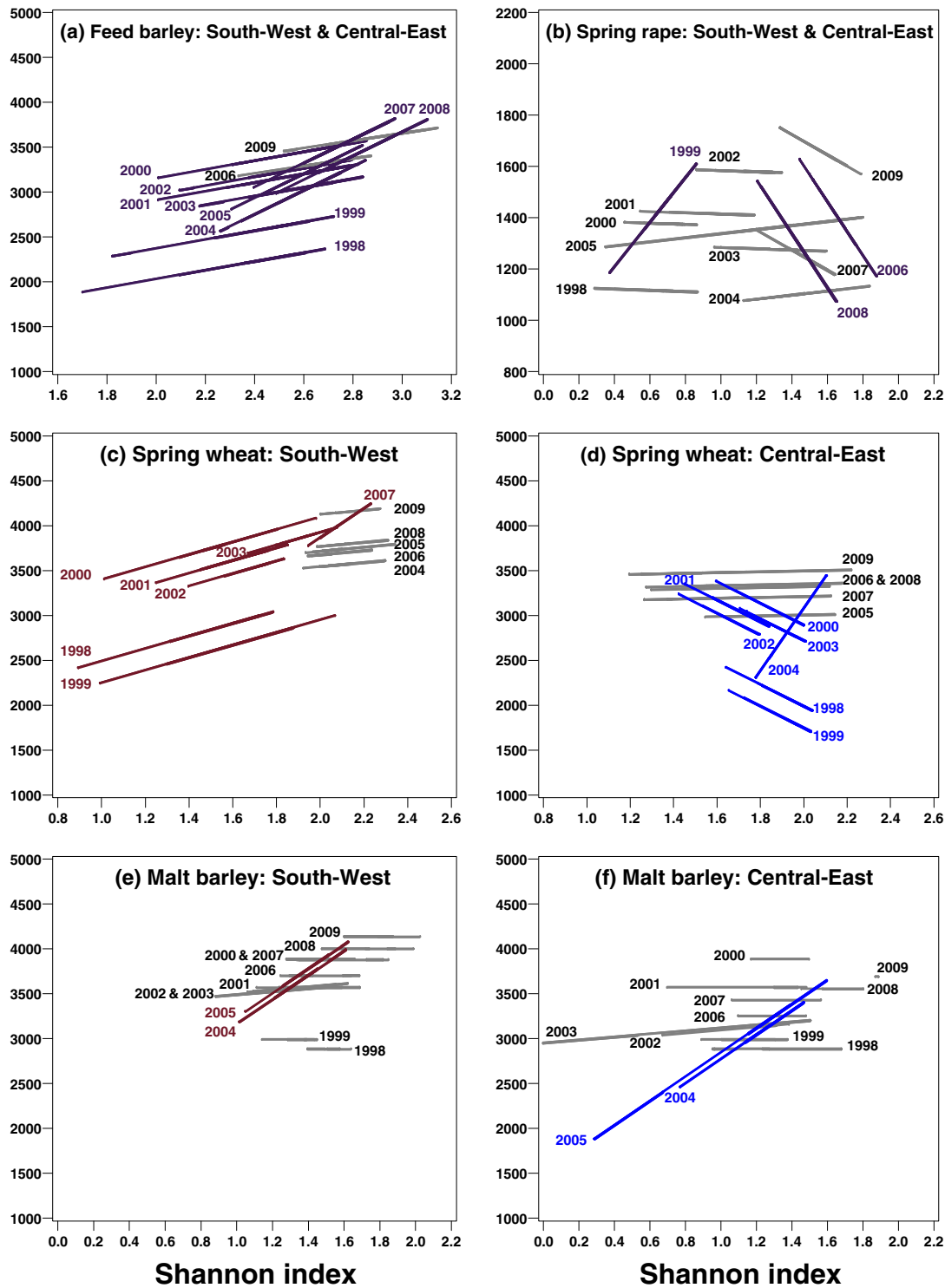
### 3.2.3 Spring wheat

The linear relationship between Shannon index and regional mean yield for spring wheat depended on the regional group in both year periods, but over 2004–2009 differently in various years (Table 1). In the south-west, a positive relationship was established over 1998–2003 (common slope=699, SE=329.4,  $p=0.04$ ) and in 2007 (slope=1,636, SE=414.6,  $p<0.005$ ), whereas in the other years the positive relationship was not significant (common slope=221, SE=547.4,  $p=0.69$ , Fig. 6c). Shannon indices in 1998–2003

were notably lower than during more recent years in the south-west region (Fig. 6c). In the central-east region, by contrast, lower mean yields were associated with higher diversity in 1998–2003 (slope=-1,215, SE=552.4,  $p=0.03$ ) and a single strong positive relationship between Shannon index and mean yield occurred in 2004 (slope=3,484, SE=510.7,  $p=0.01$ , Fig. 6d). In the remaining years, there was no evidence of the association (slope=47, SE=245.1,  $p=0.85$ , Fig. 6d).

Cultivation of spring wheat is regionally concentrated to the southern, followed by the western regions in Finland as the climatic conditions are too demanding for the crop in other parts of the country. The negative relationship between cultivar diversity and yield in the central-east region in 1998–2003 with a higher cultivar diversity than later might result from the availability of only a few regionally suitable cultivars in these marginal areas for the crop. There, an increase in regional cultivar diversity means inclusion of less well-adapted cultivars. Thus, the change from a negative association (earlier time period) between cultivar diversity and yield to no association (later time period) may stem from the central-east regions having adopted a few sufficiently well-adapted standard cultivars to grow. This was supported by the yield levels also being substantially lower during the earlier than during the later time period, and the

Mean yield (kg/ha)



**Fig. 6** Crop-specific regression lines for the relationship between regional mean yield and Shannon index describing cultivar diversity in the south-west and central-east regions in 1998–2009. The slopes, i.e., the average rates of increase in mean yield per unit increase in Shannon index ranged from 415 to 1,338 kg ha<sup>-1</sup> for feed barley (a), the only crop with solely positive relations found. For spring rape, a positive relationship was detected in 1999 (slope=869 kg), whereas a negative association was recorded for 2006 and 2008 (slope=

-1,052 kg; b). The relation between yield and cultivar diversity varied according to the regional groups for spring wheat, being positive (slopes 221–1,636 kg) in the south-west (dominant cultivation areas for the crop) and negligible or negative in the central-east (with marginal cropping and limited cultivar availability) excluding the year 2004 (c, d). For malting barley, the relationship was positive in 2004 and 2005 (slope=1,348 kg) in both regional groups (e, f). Statistically significant ( $p < 0.04$ ) relationships are represented by non-gray lines

dominance of top three cultivars increasing over the later time period (Fig. 4g). A strategy of “using the best of what is available” seemed to be most feasible in such marginal cropping areas.

In contrast, the positive relationship between cultivar diversity and yield recorded in the south-west region over 1998–2003 suggests that when yields were lower, diversification in cultivar use strengthened yields in this more climatically favorable region (as indicated by increase in cultivar number and reduction of top three share). In the case of spring wheat, similarly to spring rape, due to the small number of appropriate cultivars, cultivation of superior cultivars seemed to partly override diversification.

### 3.2.4 Malting barley

The regional mean yield of malting barley did not depend on Shannon index in 1998–2001 and 2006–2009 (Table 1). Only the average mean yields (the intercepts) differed among the years and also between the two regional groups in 2006–2009 (Table 1, Fig. 6e and f). The result was similar in 2002 and 2003 (common slope=167, SE=274.7,  $p=0.55$ ), but in 2004 and 2005 a higher Shannon index was associated with higher mean yield (slope=1,348, SE=324.1,  $p<0.001$ , Fig. 6e and f). In 2002–2005, the average mean yield differed between the south-west and central-east regions, but the slopes of the regression lines did not depend on the regional grouping (Table 1). The years 2004 and 2005 were among the years with the clearest positive relationship for feed barley as well and with heavy rainfall during the growing season (Fig. 3). Why in 2007 and 2008 was the relationship between cultivar diversity and yield negligible for malting barley, but discernible for feed barley? This might be because the cultivar Barke eclipsed Saana, a cultivar previously shown to yield less under higher than average precipitation (Hakala et al. 2012; Saana being the dominant feed barley cultivar in 2007 and 2008). The results of malting barley support the earlier findings from spring rape and spring wheat that in crops for which there is limited cultivar availability, the composition of cultivars used is more important than cultivar diversity for yield. The malting industry also largely determines the cultivars that are acceptable to use, which may limit cultivar diversification of malting barley.

### 3.3 Cultivar diversity as yield insurance

There appeared annual variation in the strength of the relationship between diversity and regional yield. Based on weather station data, 1999, 2002, and 2006 were the driest and warmest years for the studied period, whereas 1998, 2004, and 2008 were the rainiest and coldest years in the regions. These years did not appear as exceptional in our

analysis for most of the crops and thus the hypothesis that there is stronger dependence of yield on cultivar diversity (via yield insurance provision) in years with exceptional growing season was not strongly supported. However, for feed barley, the strongest relation between cultivar diversity and yield was found in 4 years (2004, 2005, 2007, and 2008) that had higher than average precipitation sum or for which exceptionally heavy rains occurred during the growing season. This suggests that specific weather changes may explain regional yields of different crops and the cultivar pool at use has to be sufficiently large for benefits from cultivar diversification to be detected. As crops vary for their most sensitive growth stage towards temperature and precipitation (Hakala et al. 2012), more targeted analysis on weather responsiveness might reveal crop-specific connections better. Variation of weather during the growing season and prevailing weather over the most sensitive time periods for individual crops and cultivars is likely to vary considerably on a regional basis. Thus, regional yields as assessed here are not easily related to such local weather variation impacts on yields. If cultivar diversity is to be used to buffer yields from weather extremes, much depends on the trait composition of the cultivars, whether they have enough phenotypic plasticity (genotype  $\times$  environment interactions) and whether there is adequate response diversity within the cultivar pool towards changes (Elmqvist et al. 2003). This should be acknowledged in building sustainable breeding strategies.

### 3.4 Constraints and opportunities for diversification of cultivar use

The extent of the available cultivar pool and regional climate can restrict diversification in cultivar use among regions. However, socioeconomic aspects affecting farm decision-making such as farmer knowhow, motivation to diversify, and economic consequences of diversification may also play a role. Crop cultivar selection on farms and regional divergence in cultivar use are influenced by numerous agronomic, economic, political, and social factors. Farm typology (including farmer age, knowledge, farm size, production line, and intensity of cropping; Reidsma and Ewert 2008) and management (Andersen et al. 2007) may reflect individual and regional motivation to diversify cultivar use or adopt novel cultivars. Plant breeding might concentrate on providing material best suited to the dominant cultivation regions or be unable to generate novel genotypes with adequate divergence from existing cultivars. Regional concentration of production and a region's comparative advantage in growing particular crops may increase incentives for adopting novel cultivars faster, but also favor dominance by only a few cultivars. Contrasting examples of this are feed barley, which is cultivated throughout Finland and cultivars vary, whereas spring wheat and malting barley cultivation is

concentrated in south-west of Finland and their cultivar use is more limited. Here, diversification on farms seems feasible and advantageous for feed barley compared to other crops, for which farmer knowledge and regional incentives in cultivar selection may vary more. Contract-based cropping may also constrain farmers' possibilities to diversify. On the other hand, diversification of cultivar use for spring rape was the highest among the crops studied, but yield and cultivar diversity were negatively related. In order to employ diversification of cultivar use as a strategy towards generating higher yield, farmer motivation alone does not suffice, and lack of a regionally adapted and differentially sensitive (Hakala et al. 2012) cultivar pool can constrain yield benefits via diversification.

#### 4 Conclusions

Diversity in the use of genotypes possesses many benefits for sustainable agriculture: diverse cultivar pool conserves valuable genetic material for the use of future generations, widens farmers' adaptation options, and sustains many ecosystem services. The novel added value from our study stems from the finding that diversification of cultivar use can be positively related to regional yield levels assuming diverse enough cultivar pool at use as was the case for feed barley. However, not in all cases was diversity beneficial. Yield traits of individual cultivars, variation in the adaptability of the cultivars used to agroclimatic conditions of particular regions and the variation in environmental responsiveness of the cultivar pool available, seem often equally or more important for yields than cultivar diversity.

Cultivar selection on farm is usually optimized for high yield under climatic normals, conditions characteristic of the region, and other features of the ecological and socioeconomic environment (Reidsma and Ewert 2008; Asrat et al. 2010). Such an optimization strategy works best in "standard" growing seasons. However, it is predicted that agroecosystems will face greater environmental variability as a consequence of global climate change (Beniston et al. 2007). As a result, crop phenotypic plasticity has a greater influence on yields. Diversity to support resilience and yield security will become increasingly important (Lin 2011). Without an adequate pool of cultivars with tolerance to many types of novel abiotic and biotic stresses, there is reduced capacity to adapt as needed (Adger et al. 2007). Based on our results especially on feed barley, cultivar diversity on farms and within regions might reduce regional and national vulnerability of cropping to particular weather incidents as well. However, the sensitivity of cultivars to different agroclimatic factors (Hakala et al. 2012) is in need of further modeling-based analyses to understand fully how to optimize regional cultivar use for provision of yield insurance.

Impacts of agriculture on the environment and sustainable provision of ecosystem services in the long term (taking into account climate change impacts), together with needs for increased productivity and positive agronomic development, need to be studied and solutions assessed in concert (Howden et al. 2007; Bennett et al. 2009). Cultivar mixtures, crop rotations, reduced intensity to support biodiversity along field margins, and widening of the regional cultivar pool used are all important, supporting means to create synergistically higher agricultural productivity and yield security. Increasing diversity at multiple levels of the cropping system, cultivar, crop, and landscape, is to be encouraged to provide security against future environmental, ecological, and economic surprises in a warming world. "Win-win" solutions that support both sustainability of farming and agricultural productivity are needed. Based on our results, diversification in cultivar use is a good candidate for such.

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