Do different tillage and fertilization methods influence weather risks on potato yield?

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Abstract. The influence of weather variability on potato yield was assessed with an aim to address different soil tillage and fertilization regimes by their weather sensibility. The strong effect of an experimental year on potato yields was proved for the experimental period; the effect of fertilization proved significant only between the highest and the lowest fertilization rates; the effect of tillage tested insignificant. If synthesized statistically over the population (over an untested period of time), significant interactions occur between years and tillage/fertilization treatments, verifying that the effect of both tillage and fertilization is dependent on year-to-year weather differences. Yields of all examined variants were found to be significantly correlated to spring weather – positively to temperatures and negatively to precipitation. Negative correlation exists between yields and temperatures summed from emergence to flowering, positive between yields and precipitation from flowering to harvest.

Key words: weather conditions, potato, fertilization, tillage

INTRODUCTION

In Estonia, like elsewhere in temperate zone, crop yield variation is highly influenced by weather conditions (Carter, 1996; Karing et al., 1999). In conjunction with spreading new, less-intensive tillage and fertilization options, it is appropriate to research their sensibility to weather fluctuations. Although the analysis of the relation between common weather parameters can hardly provide deep insight into the mechanisms of complex interrelations between weather and yield formation, it may however serve as an easily available indicator for yield estimation and evaluation (Meuwissen et al., 2000).

We used potato yields under different tillage and fertilization combinations to investigate their susceptibility to weather. The main hypothesis of this study is that the variability in meteorological conditions influences the long-term effect of different soil tillage and fertilization regime on potato yields. Another objective of the study was to analyse the relationships between yields in the long-term experiment and the common weather parameters.

MATERIALS AND METHODS

The work is based on the data of a long-term trial of soil management and fertilization methods with a six-year crop rotation (winter rye – potato – barley – barley/clover – grassland – grassland) at the Kuusiku experimental station (Viil & Nugis, 2002; Viil & Võsa, 2006), on sandy loam, Calcic Luvisol (WRB, 2006). Each range of a particular crop was divided between three parallel tillage techniques, each containing four fertilization treatments in four replications (in total 288 separate plots 10 × 5 m). In the current paper, 19 years of potato yields are examined. A plot of potato rotation contained six 10 m furrows, two central used for yield determination.

The three tillage techniques used for potato were the following: minimum tillage M1 (15–18 cm), conventional tillage M2 (22–25 cm) and deep tillage M3 (33–35 cm tillage depth). The four fertilization treatments consist of the ploughing in of the straw of the pre-culture winter rye as fertilizer with the following amounts: S0 – no straw; S1 – 4.5 t ha^{-1}; S2 – 4.5 t ha^{-1} plus 5 kg ammonium nitrate per 1 ton of straw; S3 – 9 t ha^{-1} plus 5 kg NH_4NO_3 per 1 ton of straw (background fertilization is $N_{70}P_{39}K_{75}$). The resultant 12 tillage/fertilization combinations are referred further on as M1S0, M1S1, etc.

During the run of the experiment, 3 late potato varieties bred for local conditions were grown: 1989–1992 'Eba'; 1993–2002 'Ando'; 2003–2007'Anti'.

By climate, the experimental area belongs to the continental sub-region of mainland Estonia (Jaagus & Truu, 2004), which is characterised by practically no climatic influences of the Baltic Sea. The mean annual daily temperature is 4.8 ºC (http://www.emhi.ee/?ide=6,299,302); the annual precipitation is 727 mm (..., 303). The frost-free period averages 115 days. In the current research, a time-series of average and accumulated temperatures and sums of precipitation were used. Data of single and differently grouped months, and periods between phenological phases of potato (planting, emergence, flowering and harvest) were observed (Table 1).

Table 1. Average values of observed meteorological factors at Kuusiku for experimental period 1989–2007.

Period	Precipitation, mm	Average temperature, ºC	Sum of positive temperatures, ºC	Days
March	45.7	-1.0	35.3	
April	35.8	5.0	155.7	
May	46.1	10.2	317.2	
June	70.8	14.5	435.0	
July	79.1	17.1	531.6	
August	82.6	15.9	491.8	
Planting – flowering	129.8	13.9	840.8	60.7
Emergence – flowering	72.8	15.9	489.3	31.2
Flowering – harvest	161.0	15.5	994.2	62.5

Statistica 7.0 software was used to evaluate the potato yield data. We examined the effects of tillage, fertilization and experimental year (weather) on potato yields, using one-way and three-way factorial ANOVA, allowing us to determine the possible combined effects of the variables. In the case of a significant ANOVA result, the Tukey HSD post hoc test was used to evaluate the differences among means. Also a variance components test with the experimental year as a random factor was conducted for generalisation. Since the effect of replication didn't prove significant, yields were averaged over replications. Significant yield differences between varieties were

eliminated from further analysis by normalizing yields over varieties – individual yield values were divided by mean yield values for the particular variety.

Before the factorial ANOVA, the division of experimental years into larger groups was conducted by the joining (tree clustering) tool of cluster analyses, using potato yields from 12 different tillage/fertilization combinations in those years as the measure of similarity. The method used for the calculation of clusters, the Euclidean distances method, takes into account the root-mean-square of yield differences between the years. The relations between the weather conditions and yields were analysed with linear regression analysis using a function of MS-Excel.

RESULTS AND DISCUSSION

The strong one-way effect of the experimental year on normalized potato yield was proved ($F_{18, 209} = 80.6$; $p < 0.0001$), while there was no significant one-way effect of fertilization or tillage. The division of experimental years into larger groups by cluster analysis resulted in three groups of years, with high, medium and low yields. (Fig. 1).

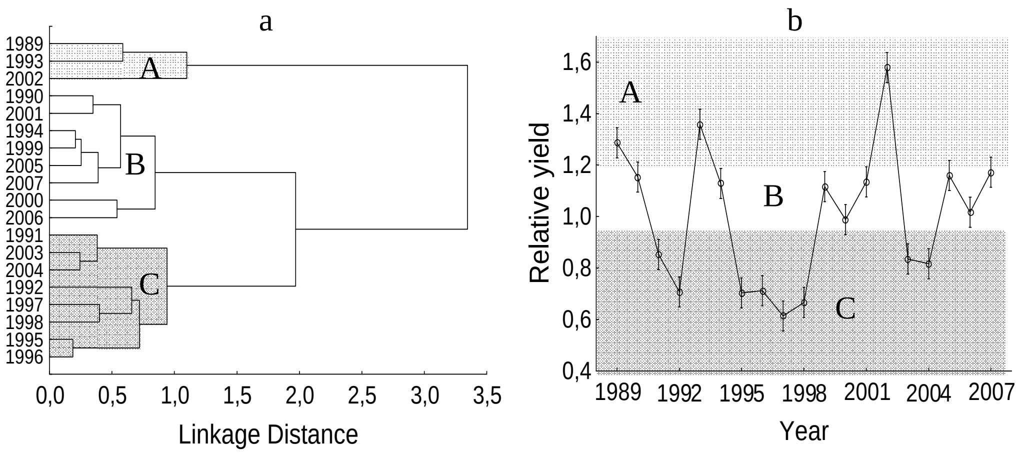

Figure 1. Classification of years into year clusters (a) and corresponding normalised yields of the years (b). A, B and C mark years with high, medium and low yields.

The integrated effect of tillage, fertilization and year clusters on relative potato yield in the experimental period is presented in the left-wing of Table 2. The insignificant effect of tillage agrees with previous results (Viil & Võsa, 2006), declaring that crop-rotational yield is only slightly or not at all affected by tillage intensity. Fertilization and year cluster proved significant, while no significant interactions between variables were detected. By the Tukey *post hoc* test, all three year clusters proved significantly ($p = 0.00002$) different from each other, while for fertilization the difference was reliable ($p = 0.0019$) only between S0 (no fertilization) and S3 (the highest fertilization) (Figure 2a). However, when three-year clusters are considered separately (Figure 2b), the difference between S0 and S3 definitely comes from the high yielding years (cluster A), confirming the effect of high fertilization for convenient weather conditions. Also in the lowest yielding years (cluster C) the positive effect of the highest fertilization treatment is detectable. The negative effect of no fertilization appears for the years with high and medium yields; for the highest yield years also S2 tends to have negative impact.

Table 2. The effect of tillage, fertilization and experimental year on potato yields presented by three-way factorial ANOVA. Year cluster is used as a fixed variable for sample (on the left); year as a random variable for population (on the right).

	Effect on sample				Effect on population					
Impact	*df*	*MS*	*F*	*P*	*df* effect	*MS* effect	*df* error	*MS* error	*F*	*P*
Tillage	2	0.0085	0.53	0.6	2	0.009	36	0.020	449	0.64
Fertilization	3	0.11	4.50	0.0004	3	0.98	54	0.017	5.65	0.002
Year cluster / year	2	6.85	216	<0.0001	18	0.85	74	0.035	23.94	<0.0001
Tillage×fertilization	6	0.0015	0.05	0.99	6	0.0017	108	0.002	0.83	0.55
Tillage×year cluster / ×year	4	0.013	0.36	0.54	36	0.02	108	0.002	9.94	<0.0001
Fertilization×year cluster / ×year	6	0.028	1.30	0.13	54	0.017	108	0.002	8.50	<0.0001
Error	192	0.017								

df – degree of freedom; *MS* – mean square; *F* – the ratio of the *S*-squares; *p* – level of significance

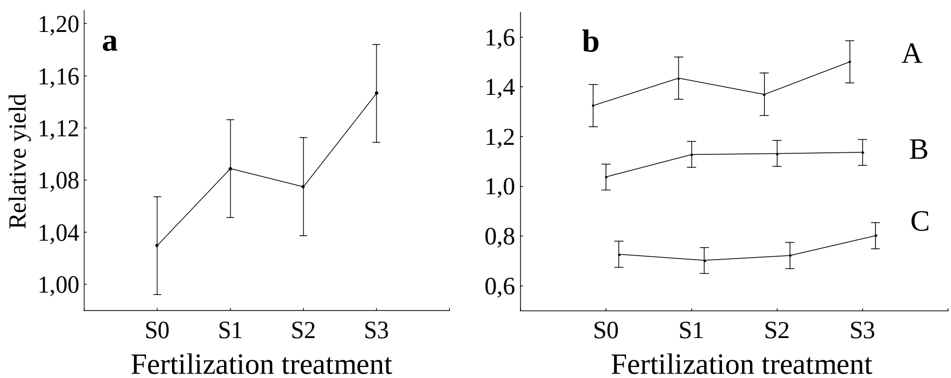

Figure 2. Least squares mean yields of fertilization treatments (a) and the same yields differentiated by year clusters of high (A), medium (B) and low (C) yields (b). Vertical bars denote 0.95 confidence intervals.

However, one should notice we are treating experimental year here as a fixed factor, thus the results only apply within the observed years. To generalize results over the years outside the given sample (statistically – over the population), we performed analyses of variance with fertilization treatment and tillage as fixed factors and experimental year as a random factor, presented in the right-wing of table 2. Outside the range of the observed years, the effect of experimental year still remains very important (describing over 80% of the yield variance) and tillage still doesn't matter; the effect of fertilization decreases slightly and reliable interactions with experimental year appear both for fertilization and tillage. We can say that "in the real world" the effect of both fertilization and tillage depends on the particular year with specific conditions. To learn more about this, individual years' weather data are related with yields (Table 3).

Table 3. Linear correlations between average yields of 7 different variants (M1, M2, M3 averaged over fertilization variants; S0, S1, S2, S3 averaged over tillage range) and meteorological elements of different periods. Bold indicates significance $p < 0.05$.

Period	Element	Variant						
		M1	**M2**	**M3**	**S0**	**S1**	**S2**	**S3**
January	Average temperature	0.38	0.33	**0.46**	0.35	0.37	0.36	**0.47**
April – May	Average temperature	**0.71**	**0.71**	**0.76**	**0.71**	**0.69**	**0.71**	**0.77**
	Sum of precipitation	**-0.44**	**-0.48**	**-0.46**	**-0.54**	**-0.42**	**-0.44**	**-0.44**
Planting – flowering	Sum of temperatures	**-0.49**	**-0.57**	**-0.53**	**-0.65**	**-0.48**	**-0.49**	**-0.50**
Flowering – harvesting	Sum of precipitation	**0.57**	**0.57**	**0.63**	**0.60**	**0.55**	**0.59**	**0.62**

The regression analysis showed the strongest correlations between yields and average temperatures in spring, with positive correlation coefficients over 0.7 for the period April – May. Yield was more influenced by temperatures for deep tillage and high fertilization treatments, which derives from May temperatures. Positive correlations between yields and average temperatures in January probably derive from the influence of January temperature on spring conditions through its interactions with the snow and ice cover (Tooming & Kadaja, 2006). This correlation is only significant for deep tillage and high fertilization, indicating the stronger weather effect in the case of strongly managed variants. Since the potatoes were not planted until May, the positive effect of early spring temperatures comes through the warming and early drying of the soil. Negative correlation exists between yields and accumulated temperatures between planting and flowering. This effect probably proceeds from low temperatures prolonging the period between the two phases and raising the risk of damage to the sprouts by damping-off. The results of the regression analysis suggest the positive effect of higher temperatures before and around the time of planting and early growth of potatoes, which is a precondition of high yields. The effect is evidently mediated by the soil but as the soil temperature of the top layer is closely related to air temperature, the latter serves as a good indicator. Also Haberle & Iviic (2006) found that the average temperature around planting time is strongly related to potato yields.

The correlations between yields and precipitation are weaker than those with temperatures. Reliable ($p < 0.05$) negative correlation occurs for all variants with precipitation summed from April till May; this relation derives primarily from May precipitation and is stronger within the high yielding years and not fertilized variants. The lack of a (positive) effect of precipitation in spring and during early growth is probably connected with lower temperatures during rainy periods (Feddes, 1987) and slower warming of the soil, which is supported by a negative correlation between rainfall and temperature. The result is that warm, dry springs are more favourable for potato growth than wet, cold springs. On the other hand, potatoes demand favourable physical soil conditions (aeration) that are difficult to attain during rainy springs, and they show a higher level of optimum water content than other crops. Potatoes are more susceptible to water stress during their tuber formation period in July and August, granting positive correlation between yields and precipitation summed from flowering to harvest.

CONCLUSIONS

- Potato yield variance is determined mainly by weather conditions; fertilization treatments also have an effect, while observed tillage methods induce no significant differences.
- In longer perspective, both fertilization and tillage affect the influence of weather on yields.
- The fertilization-induced yield differences manifested most noticeably in years with favourable growing conditions.
- Of meteorological conditions, potato proved the most susceptible to spring temperatures, yielding higher in years with a warm spring; negative relation between yields and precipitation during the same period concurred.
- The positive influence of precipitation was expressed after flowering.

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