ANALYSIS OF GRAIN YIELD IN THIRTY YEARS OF SOYBEAN CULTIVATION IN NORTH-EAST ITALY

TRENT'ANNI DI COLTIVAZIONE DELLA SOIA IN FRIULI: TREND PRODUTTIVO

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Abstract

This study analyses grain yields of soybean monitored in the variety trials performed in North-East Italy from 1983 to 2015 by ERSA FVG in order to evaluate the existence of yield trends and how inter-annual yield oscillation could be explained either by meteorological, genetic or agronomic factors. In this period, about 400 varieties have been tested and, despite of agricultural inputs reduction and little change of genotypes, statistical analysis underlines an average yield increase of about 30 kg ha^{-1} year^{-1}. The regression analysis suggests that the average daily thermal excursion explains inter-annual yield variations much more than other environmental variables (rain and soil characteristics). In conclusion, the higher yields observed in the last years seem mostly due to both environmental conditions and improved cultivation techniques.

Keywords: soybean yield, trend, climate, agricultural practices, variety.
Parole chiave: resa soia, trend, clima, tecniche agronomiche, varietà.

Introduction

In Italy, soybean cultivation heavily started only after the recognition of its strategic importance by the EU during the '70. Ten years later, crop management techniques were deeply studied and adapted to most Italian environments in the framework of "Progetto Oleaginose", funded by MAF (now MIPAAF, Ministero delle Politiche Agricole Alimentari e Forestali). Since 1983, Friuli Venezia Giulia (North-East of Italy) was among the Italian regions with the highest densities of soybean cultivation, as well as the highest grain yield per ha. Moreover, together with an intensive testing of soybean varieties, ERSA (Agenzia Regionale per lo Sviluppo Rurale del Friuli Venezia Giulia) also carried out breeding programs leading to the release of several successful soybean varieties.
This work provides an analysis of the thirty-year ERSA results of soybean variety trials, with the purpose of investigating trends and variability in soybean grain yield. Another topic of the work is to improve the knowledge about the driving forces of these variations, considering that soybean yields are the result of multiple interactions of genetic, pedo-climatic and agronomic factors.

Materials and methods

Experimental trials

Soybean yield data (t ha^{-1}, 13% of moisture), of the national variety trials carried out from 1983 to 2015, were recovered from the archives of ERSA FVG. The trial sites were located in the Friuli Venezia Giulia plain, in the provinces of Udine and Pordenone. The trial locations and their soil characteristics are reported in figure 1 and table 1, respectively. The experimental plots were arranged in either randomized blocks (4 replications) or complete randomization (5-6 replications) design. Plant density ranged from 35 to 45 plants m^{-2}. The sowing date ranged from 24/04 (Palazzolo, 2007) to 12/06 (Palazzolo, 2013), with most of the sowing times in May; harvest occurred from 22/09 (Palazzolo, 2011) to 17/11 (Pozzuolo, 1994) with most of the harvests in October. Irrigation was generally applied two or three times (supplementary irrigation), depending on the rainfall frequency and amount. Treatments for pests control were occasionally applied. Weed control was performed by pre- and post-emergence herbicide treatments. Soil fertilization (about 25 kg ha^{-1} N, 100-120 kg ha^{-1} P_2O_5 and 100-120 kg ha^{-1} K_2O) was made until 1998; in the following years, no fertilizers were applied. Seeds were always inoculated with the specific rhizobium, in order to ensure a good nodulation and N-fixation.

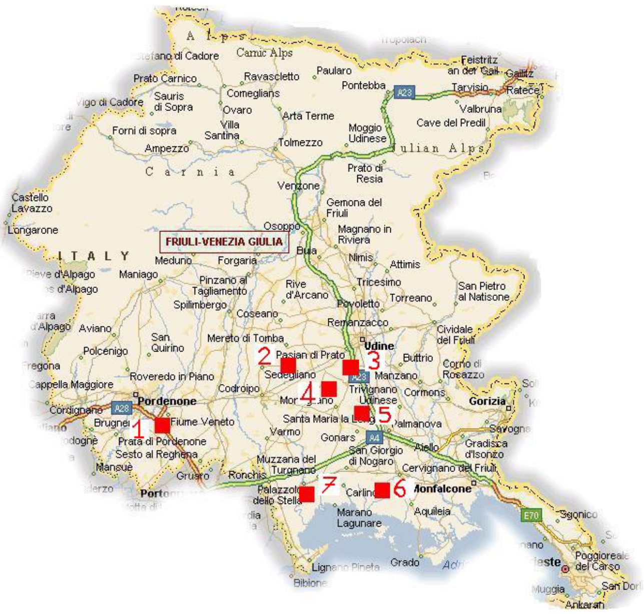

Fig. 1: Location of the trial sites.
Fig. 1: Localizzazione dei siti sperimentali.

In most cases, previous crop was maize; less frequently, sugar beet, soybean, barley and wheat. About 400 varieties, selected from those registered in the Italian Registry of varieties, were tested in the thirty-year period; until 2000, tested varieties belonged to maturity groups ranging from 00 to II, afterwards, to maturity groups ranging from 0+ to I+.

Meteorological and soil data

The following meteorological variables have been retrieved from the regional meteorological service (OSMER) dataset: daily rainfall (mm d^{-1}), daily minimum and maximum air temperature (°C); daily thermal excursion (°C) has been calculated as a proxy for solar radiation, not available for all years. Cumulated rainfall (*Rain*, mm/period) and mean thermal excursion (*ΔT*, °C) for each month from April to August, and for the whole period, have been calculated per each experiment (year x site).

Tab. 1: Trial sites and main soil properties.
Tab. 1: Siti di prova e principali caratteristiche pedologiche.

Trial site	Organic matter [% v/v]	Wilting point [% v/v]	Field capacity [% v/v]	Max. water content [% v/v]	CSC [mEq/ 100g]	Texture class (USDA)
1 FiumeVeneto	2.6	21.8	28.1	48.2	30.3	silty-loam
2 Basiliano	2.6	14.1	19.1	42.0	26.5	loam
3 Pozzuolo d.F.	2.6	22.0	28.8	48.2	36.0	clay-silty-loam
4 Mortegliano	2.3	15.0	21.1	41.2	26.0	silty-loam
5 Bicinicco	6.6	17.7	24.4	51.3	37.4	loam
6 Torviscosa	2.4	15.9	22.0	43.8	30.4	loam
7 Palazzolo d.S.	2.4	16.6	24.1	47.2	29.8	silty-loam
Mean	3.1	17.6	23.9	46.0	30.9	-

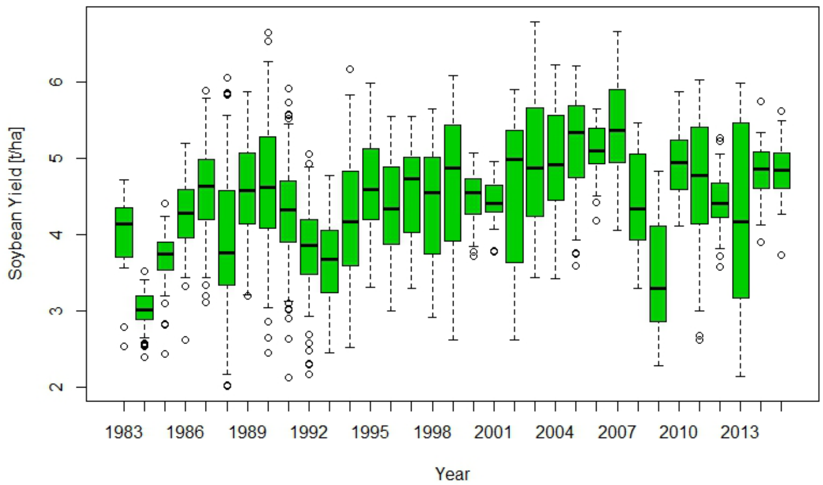

Fig. 2: Boxplot of soybean grain yield distribution (t ha^{-1}) of all cultivar tested in all the sites, in each year.
Fig.2: Boxplot delle distribuzioni delle rese (t ha^{-1}) di tutte le varietà di soia in prova per tutti gli ambienti, per ciascun anno.

Statistical analysis

In figure 2, boxplots return the variability of soybean yields per year, for all varieties and sites. The lower and upper limits of each box represent, respectively, to the first and third quartile of yields, while the black strip indicates the median. Dots represent the outliers. The graph emphasizes a large variability of soybean yields in the period. In some years (e.g. 1983, 1997, 1999 and 2010), the upper half of the boxes is shorter that the lower, meaning that in these years high yield values are more similar than the lower ones. In other years (e.g., 1988, 2001, 2009) a reverse behaviour occurred. For these reasons, in the present study only the third quartile of soybean yields (*Yield3q*) has been tested to underline the presence of a trend over the years. These values were analysed using multiple regression models involving the variable *Year* and the available meteorological variables, calculated for each month of the soybean growing season (April-August) and for the whole period, as previously described, in order to better understand the role of these variables.

Furthermore, three indexes have been calculated in order to evaluate the rate of cultivars turn-over in the years: (a) rate of drop (*Raba*=*Na*/*Nv*), (b) rate of introduction of new varieties (*Rnew*=*Nn*/*Nv*), and (c) rate of cultivar change (*Rcvc*=(*Na*+*Nn*)/*Nv*), where, for each year, *Na* is the number of varieties no more tested, *Nn* the number of newly introduced varieties and *Nv* the total varieties tested each year.

Results and discussion

A first order regression model between the third quartile of soybean yields and the variable *Year* provides the evidence of an annual trend (figure 3). Both the intercept and the explicative coefficients are significant (p-values are respectively 0.0007 and 0.0003) even if the explained variability is very low (R^2 = 0.17). The estimated regression coefficient for the variable *Year* indicates an average yield increase of about 31 kg ha^{-1} per year. This result agrees with data obtained in USA, showing a mean annual yield increase of 25 kg ha^{-1} (Irwin and Good 2014).

To assess the effect of meteorological conditions on yield variations (beside year), a multiple regression model, calculated per each month of the soybean growing season, has been estimated.

[illegible]

The significance of the estimated coefficents and the RMSE of regression models are presented for each month in table 2. As expected, the estimated coefficients for the variable *Year* are always significant, accordingly to the trend described before. The estimated coefficients for the variable *Rain* are significant only in the months of April and May and not in June and July. This result could be explained considering that soybean is sensitive to drought even at the early stages (mainly due to the symbiosis with rhizobium) and that the supplemental irrigations were usually applied during the flowering and accumulation stages, occurring from late spring to summer, when the correlation with rain was not found. Thermal excursion ([illegible]) significantly contributes to the explanation of yields in all months other than August. Considering that thermal excursion is correlated to the

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availability of solar radiation, this variable could be considered as a proxy of this physical quantity. Actually, in the last years, an increase of global solar radiation from maximum values of 25 to about 30 MJ m^{-2} d^{-1} was observed due to climatic changes.

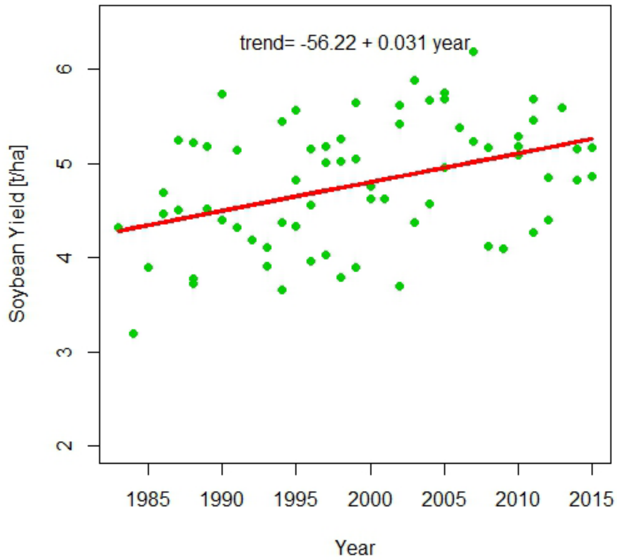

Fig. 3: Yield trend of third quartile.
Fig. 3: Andamento della produttività negli anni (terzo quartile).

Tab. 2: Statistical significance of the multiple regression parameters related to the different meteorological variables.
Tab. 2: Significatività statistica dei parametri della regressione multipla relativi alle diverse variabili meteorologiche.

Month	Year	Rain [mm $month^{-1}$]	ΔT [°C]	RMSE [t ha^{-1}]
April	***	**	***	0.576
May	***	*	**	0.596
June	***	ns	*	0.613
July	*	ns	***	0.597
August	***	ns	ns	0.626

Varietal changes are represented in figure 4 with the indexes *Rcvc*, *Raba* and *Rnew*. During the '80 and the early '90 a wide introduction of new soybean varieties occurred, as demonstrated by high values of all indexes. Since 2000, the number of dropped varieties and new introductions in the trials decreased. It is likely to argue that this reveals the identification of the most suitable soybean varieties for FVG environmental conditions.

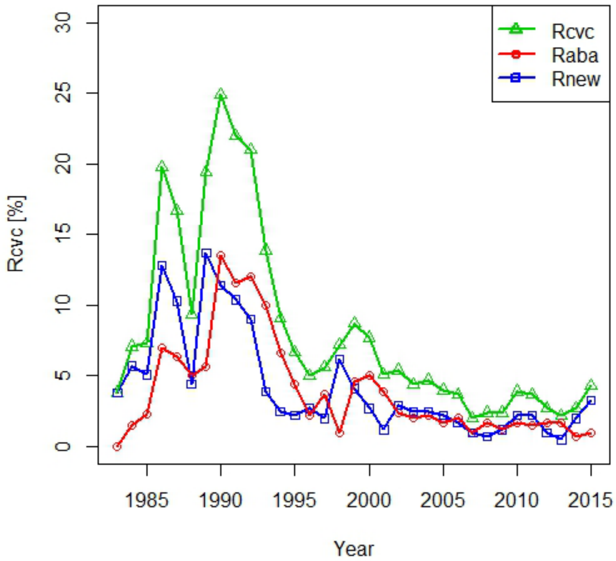

Fig. 4: Rate of varietal change (Rcvc), varietal abandon (Raba), and varietal new introduction (Rnew) per year.
Fig. 4: Tasso di cambio varietale, abbandono varietale e di nuove introduzioni per anno.

Conclusions

A first attempt to analyze the evolution of soybean yields in the last 30 years in Friuli Venezia Giulia region has been made. It highlights the presence of an increasing annual trend in soybean yields. Regression analysis showed the importance of water availability in April (owing to soybean sensitivity to water shortage in the early stages due to less N-fixing activity) and of global radiation in summer.

Statistical models developed to explain the variability of yields around the trend contribute in defining the role played by the explicative variables, even if a satisfying level of knowledge is not still completely achieved. Future perspectives can involve other meteorological, soil and agronomic variables towards a better understanding of the phenomenon.

In conclusion, the significant yield increase observed in the last thirty years seems not be due to the genetic improvement (with a limited variety change after 2000), but mainly to better agricultural practices and, perhaps, to increased solar radiation. Moreover, the validation of meteorological datasets could represent a starting point for future improvements of the regression models and for new related approaches.

References

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Acknowledgements

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