PROBABILISTIC YIELD FORECAST BASED ON A PRODUCTION PROCESS MODEL

Jüri Kadaja*, Triin Saue, Peeter Vii[1]

[1] *Department of Agricultural Engineering and Technology, Estonian Research Institute of Agriculture, Saku, Estonia 75501*

* *Corresponding author, Address: Department of Agricultural Engineering and Technology, Estonian Research Institute of Agriculture, Saku 75501, Estonia, Tel: +372 6711 554, Fax: +372 6711 540, E-mail: jyri.kadaja@eria.ee*

Abstract: A method for probabilistic forecast of agricultural yield depending on meteorological variability, i.e. forecast of agrometeorological resources, is discussed. Forecast is based on the category of meteorologically possible yield (MPY)–the maximum possible yield for a given variety in the existing meteorological conditions. The forecasting process is realized by a potato production process model POMOD, which applies the principle of maximum plant productivity and method of reference yields. The yield diversity, granting probabilistic distribution was obtained from series of model calculations, whereby the weather realizations for post-forecast period were gained from a century-long meteorological data series. Three examples realized for extremely different years are discussed. The results of such forecast, presented as a cumulative distribution, allow user to adjust and plan activities to the sufficiently assured yield level. Forecast of agrometeorological resources can be transformed to the forecast of real commercial yield (CY) by incorporating the efficiency coefficient of using meteorological conditions (CY/MPY).

Keywords: probabilistic yield forecast, agrometeorological resources, crop modelling, yield categories, potato

1. INTRODUCTION

As widely acknowledged, probabilistic weather forecasts have essential advantages compared to the categorical ones, providing users with a potential range of weather-related risks and benefits. The same holds true for the prognosis in agricultural meteorology. By nature, the yield of agricultural crop is indefinite before its maturity, and the degree of this indefiniteness is mostly determined by the time interval of undefined environmental conditions and their site-specific variability. Not surprisingly, in agricultural meteorology probabilistic relationships between crop yield and environmental conditions are long since studied. For instance, distributions and cumulative distributions of agrometeorological factors have been determined in several agrometeorological handbooks (e.g. Agroclimatic …, 1974). Probabilistic relationships of yield with solar radiation accumulation and water conditions were investigated by Tooming and Kõiva (1979). In nineteen eighties, the probabilistic approach to the agrometeorological yield forecast was introduced by Zhukovsky and Uskov (1984), Sepp (1988), Kuchar (1989), more accurately and concisely this method was defined in the common publications of Zhukovsky, Sepp and Tooming (Zhukovsky et al., 1989, 1990).

The principle of probabilistic yield forecast is to calculate crop production, using real meteorological data up to the forecast moment and different weather realizations, assessed either by weather conditions of previous years (Sepp, 1988; Zhukovsky et al., 1989, 1990), generated weather data (Zhukovsky et al., 1992; Dubrovsky at al., 2002), or ensembles of seasonal weather forecasts (Cantelaube and Terres. 2005; Challinor et al. 2005).

The aim of this investigation was to give a probabilistic yield forecast scheme depending on meteorological variability only, with other words a probabilistic forecast method for agrometeorological resources. To describe and calculate the separate influence of meteorological conditions to the yield, we need to exclude the impacts of soil, landscape or management. Such distinctions can be derived from the categories of the method of reference yields, introduced by Tooming (1982, 1984, 1993) and developed in (Zhukovsky et al. 1989). In the present paper, we describe the realization of the reference yields method into the probabilistic forecast of agrometeorological resources carried out on the basis of potato production model POMOD (Sepp and Tooming 1991; Kadaja and Tooming 2004).

2. MATERIALS AND METHODS

Proceeding from the method of reference yields (Tooming, 1982, 1984, 1993), which is respectively based on the principle of maximum plant productivity (Tooming, 1967, 1970), the maximum production and yields are observed under different limiting factors divided into agroecological groups: in general into biological, meteorological, soil and agrotechnical groups. These groups are included in the model separately, step by step, starting from optimal conditions for the plant community (Tooming, 1975, 1977, 1984, 1993, 1998; Zhukovskij et al. 1989; Sepp and Tooming 1991; Kadaja and Tooming, 2004). The main categories of reference yields are, in descending order, potential yield (PY), meteorologically possible yield, practically possible yield (PPY) and commercial yield (CY) (Fig. 1). This set of yield categories gives us an ecologically based reference system for comparison and analysis of different yield values obtained from field trials as well as from model experiments. Additionally, each of these categories represents particular kind of ecological resources for plant growth expressed in yield units.

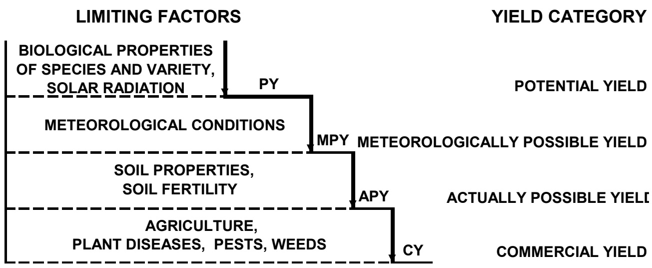

Figure 3. Hierarchy of reference yields, and limiting factors taken into account in each

The PY is determined by the biological properties of the species and variety and radiation resources available for utilisation. This yield category practically expresses the solar radiation resources for cultivating a given variety in yield units. The MPY, the main subject of interest in this study, is the maximum yield conceivable under the existing irradiance and meteorological conditions with optimal soil fertility and agrotechnology. MPY expresses agrometeorological resources, its mean value over a long period characterises agroclimatic resources in yield units. PPY is the maximum yield achievable under the existing meteorological and soil conditions, if soil tilling is optimal, the influence of plant diseases, pests and weeds is absent. CY is the yield attainable under existing farm conditions, if all the factors limiting the production process are taken into account.

In the frames of reference yields, the ratio CY/MPY is referred as efficiency coefficient of using meteorological conditions, characterizing which part of agrometeorological or agroclimatic resources is really used in existing soil and agricultural conditions.

In this work, the probabilistic yield forecast is realised on the basis of potato production model POMOD (Sepp and Tooming, 1991; Kadaja and Tooming, 2004), developed for computation of PY and MPY. The model is parameterised for late variety Anti based on the field experiments at Saku

(N 59°17´; E 24°37´) in 2001–2004 (Kadaja, 2004) and at Kuusiku (N 58°59´; E 24°42´) in 2005–2007.

Meteorological datasets of Tartu-Tõravere station (up to 1996 adjacent to Tartu N 58°18'00" E 26°43'48", from 1997 at Tõravere N 58°15'50", E 26°27´42´´) from 1901 to 2007 are used as meteorological realizations. Daily data of temperature, precipitation and global radiation were used. As direct measurements of global radiation exist only since 1954, missing daily sums were calculated from sunshine duration, using regression equations established separately for every month. The beginning of growing period in spring is determined by the permanent rise of temperature above 8 °C or the fall of soil moisture below field capacity, the end in autumn by the permanent drop of temperature below 7°C or by the first night-frost ≤ -2°C. The data of soil water status in spring were collected from the reports of agrometeorological network. For the earlier period (up to the end of the 1940s) and for some last years when the agrometeorological network was not working, the fall of soil moisture below field capacity was derived on the basis of meteorological data at the stations. Hydrological parameters of Albeluvisol (WRB), sandy silt loam, the soil prevalent for the locality were applied (Kitse, 1978).

In this example we calculated and analyzed probabilistic forecasts for three years: a well balanced 2007, a dry 2006 and a wet and gloomy 1998. We observed four forecast dates, the last days of May, June, July and August.

3. RESULTS AND DISCUSSION

The time series of meteorologically possible yield (Fig. 2a) do not have any statistically significant trend for the period 1901–2007. Therefore, the distribution of MPY can be interpreted as climatic probabilistic yield forecast given before sowing date for the observed location. The probabilistic forecast is well illustratable by cumulative distribution giving maximum probability to the smallest (it is the most highly assured yield) and minimum probability to the highest yield (Fig. 2b). Uncertainty of probabilistic forecast depends on the number of weather realizations *N*. Probability, that the yield under prediction will be outside the computed limits is 1/N, with probability 1/2N lower than the smallest yield value from the calculations and with probability 1/2N higher than the highest. Therefore, the uncertainty of the climatic probabilistic forecast in case of 107 different realizations is 0.94%, i.e. in future the MPY with a probability 0.0047 can be expected below and with the same probability above the limits presented by the cumulative distribution curve on Fig. 2b.

The climatic probabilistic forecast of the MPY is not symmetric in Tartu. Average of the yield series is 55.6 Mg ha^{-1}, median of the distribution is

58.6Mg ha^{-1}. The MPY values slightly above average are prevalent, while the highest MPY values corresponding to the near ideal meteorological conditions are quite rare. Span of yields below median is markedly wider than these of above. The lowest yields in the series below 30 Mg ha^{-1} are related to excessively wet years, 1928, 1985 and 1998, whereas the MPY values between 30 and 40 Mg ha^{-1} are mostly affected by dry conditions. Primarily, the climatic probabilistic yield forecast is a characteristic of the location, allowing comparing different regions for their favourableness and risks for growing a crop or variety in the long-time perspective.

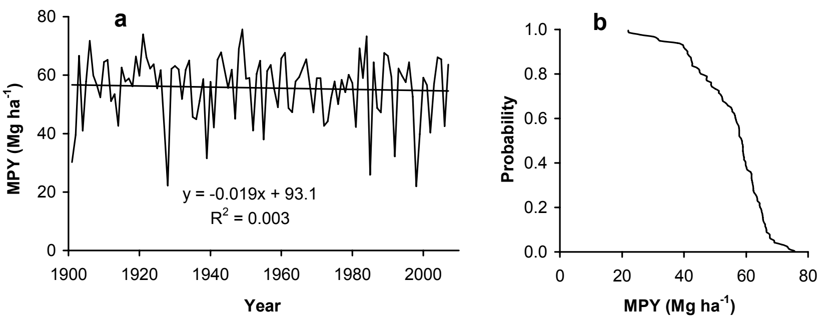

Figure 4. Time series of meteorologically possible yield from 1901 to 2007 (a) and its cumulative distribution – climatic probabilistic forecast of MPY (b)

In particular computations of probabilistic forecasts for 1998, 2006 and 2007, only the meteorological data of previous years were used, therefore the numbers of realisations are 97, 105 and 106, respectively.

The year 1998 was extremely wet in Tartu region, resulting in the lowest MPY of the last century. The forecast at the end of May, having yet quite good conditions for potato, did not contain any realizations in the ensemble matching to the final MPY of the year (Fig 3). The predictability of so low yield was across the limits of uncertainty then, less than 0.51%. The next month, June, was extra wet with precipitation exceeding the normal 2.7 times. The MPY values of computed ensemble decrease markedly to the end of June (Fig. 3) and yields assured with 80–90% probability are nearly two times lower than forecasted at the end of May (Fig. 4). Probability to get the yield equal to the final MPY was about 2% at the end of June. Two following forecasts reflect further worsening of the conditions during July and August, contributing to the excess water by 50% above normal precipitation. At the end of July, the final poor yield level or below it was predicted with 20% probability. At the end of August the forecast gave predominantly slightly lower yields than the final MPY, i.e. in September the very bad meteorological conditions of the summer were a little adjusted.

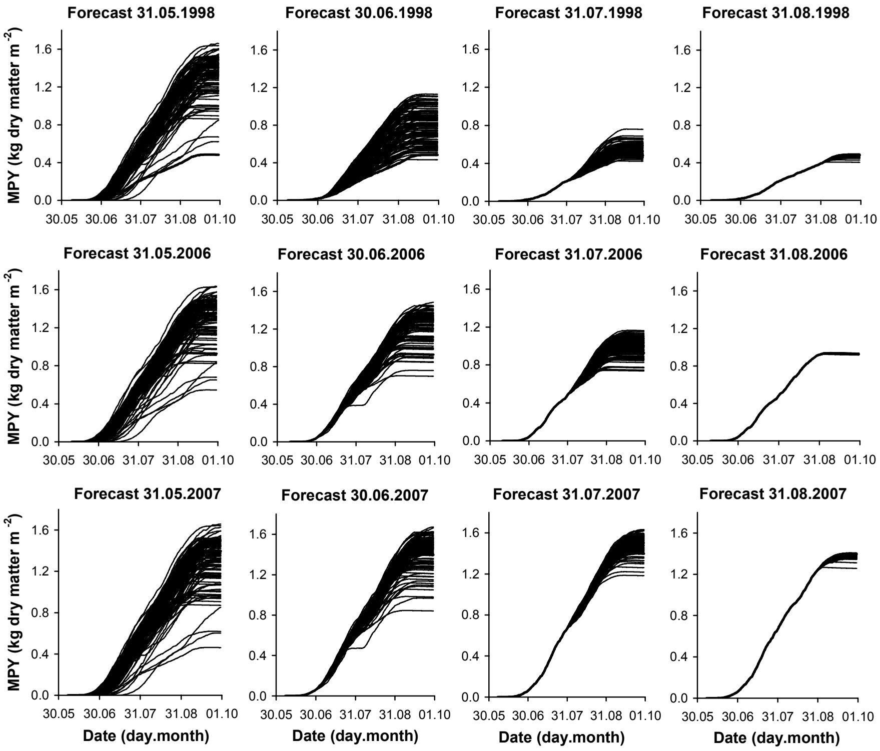

Figure 3. Ensembles of yield accumulation trajectories computed at different forecast dates for excessively wet 1998, droughty 2006 and quite well balanced 2007 years. Thick line indicates the yield accumulation computed by the data of forecasted year

In 2006 the shift of forecasts to the lower yields from month to month is caused by dry conditions having the strongest impact in July (Fig. 4). In 2007, the forecasts indicate improving yield promise up to the end of July due to fall-off probabilities for low yields. However, the dry and warm weather at the first half of August did not allow a peak of yield series in this year, removing higher realizations from the forecast ensemble already at the end of August.

Comparison of the forecast ensembles from the end of May of different years (Fig 3), and the corresponding cumulative distributions (Fig. 4) indicates that the forecasts from this date are quite similar, predicting slightly higher yields than climatic forecast in observed years. At the end of May, the span of yields is in average only 6% narrower than the range of climatic forecast certifying that such an early prediction does not improve the climatic forecast sufficiently. By the end of June the predicted range of yield decreases by 1.5 times, and three times by the end of July. The predictability qualifies quite highly in the last date. Although the tubers mass mostly accumulates in August, the general condition of plants is sufficiently determined in July. By the end of August the range of predicted yields has decreased approximately 30 times in average, but usually for this time the growing period is almost over and September does not add much increase.

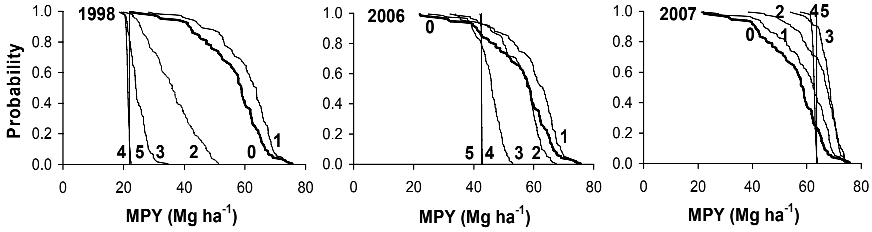

Figure 4. Probabilistic forecasts of meteorologically possible yield of potato at four forecast dates for 1998, 2006 and 2007 years, completed with climatic probabilistic yield forecast and the final MPY of the particular year

***0** – Climatic forecast, **1** – 31. May, **2** – 30. June, **3** – 31. July, **4** – 31 August, **5** – Final yield*

On this basis, the prediction of real yield in production, or commercial yield (CY), is realizable, by applying efficiency coefficient of utilizing meteorological resources (EUM). EUM is computable as the ratio between CY and MPY from previous years. Certainly, the spatial aspect must be assured – to give a forecast for a certain area, both the determined CY and calculated MPY must either correspond to the same location (e.g. field), or be the spatial means from given area (e.g. district, state). If actual CY values are available for a prolonged period, the trend in the series of EUM is convenient to calculate its value for the forecast year.

ACKNOWLEDGEMENTS

This study was funded by the Estonian Science Foundation grant No. 6092

REFERENCES

Agroclimatic resources of Estonian SSR. Gidrometeoizdat, 1974, 174 p. (In Russian).

Cantelaube P., Terres J.M. Seasonal weather forecasts for crop yield modelling in Europe. Tellus Ser A Dyn. Meteorol. Oceanogr., 2005, 57: 476–487.

Challinor A.J., Slingo J.M., Wheeler T.R., Dobias-Reyes F.J. Probabilistic simulations of crop yield over western India using the DEMETER seasonal hindcast ensembles. Tellus Ser A Dyn. Meteorol. Oceanogr., 2005, 57: 498–512.

Dubrovsky M., Zalud Z., Trnka M., Pesice P., Haberle J. PERUN - The System for the Crop Yield Forecasting. in: XIV Czecho-Slovak Bioclimatological conference, 2–4. September 2002, Lednice, Czech Rep. CD-ROM proceedings.

Kadaja J. Influence of fertilisation on potato growth functions. Agronomy Research, 2004, 2zz1): 49–55.
Kadaja J., Tooming H. Potato production model based on principle of maximum plant productivity. Agric. For. Meteorol. 2004, 127(1–2): 17–33.
Kitse E. Mullavesi [Soil water]. Tallinn, Valgus, 1978, 142 p. [In Estonian].
Kuchar L. The exponential polynomial model (EPM) of yield forecasting for spring wheat based on meteorological factors and phenophase. - Agric. For. Meteorol, 1989, 46: 339–348.
Sepp J. Effect of meteorological conditions of different periods on potato productivity and the probabilistic yield forecast. Proceedings of All-Union Research Institute of Agricultural Meteorology. Leningrad, Gidrometeoizdat, 1988, 23: 116–122. (In Russian).
Sepp J., Tooming H. Productivity resources of potato. Gidrometeoizdat, Leningrad, 1991, 261 p. (In Russian).
Tooming H. Climate change and estimation of ecologically founded yields. In: T. Kallaste and P. Kuldna (Eds.). Climate change studies in Estonia. Ministry of the Environment Republic of Estonia, SEI, Tallinn, 1998, pp. 141–152.
Tooming H. Ecological principles of maximum crops productivity. Gidrometeoizdat, Leningrad, 1984, 264 p. (in Russian, summary in English).
Tooming H. Evaluation of agrometeorological resources based on the potential productivity of crops. Journ. Agric. Met. (Jap.), 1993, 48 (5): 501–507.
Tooming H. Kõiva P. Agroclimatic estimation of the potential and actually possible potato yield. Meteorologiya i Gidrologiya (Meteorology and Hydrology), 1979, (7): 105–109. (In Russian).
Tooming H. Mathematical description of net photosynthesis and adaptation processes in the photosynthetic apparatus of plant communities. In: Setlik I. (Ed.), Prediction and Measurement of Photosynthetic Productivity. Pudoc, Wageningen, 1970, pp. 103–114.
Tooming H. Mathematical model of plant photosynthesis considering adaptation. Photosynthetica, 1967, 1(3–4): 233–240.
Tooming H. Prospects in forecasting the efficiency of changing the plant parameters and the estimation of maximum yield. In: Programming of agricultural crops yield. Kolos, Moscow, 1975, pp.403–414. (In Russian).
Tooming H. Solar radiation and yield formation. Gidrometeoizdat, Leningrad, 1977, 200 p. (In Russian, abstract in English).
Tooming H. The method of model yields. Vestnik Sel'skokhozyaistvennoi Nauki (Reports of Agricultural Sciences), 1982, (3/306): 89–94. (In Russian).
Zhukovsky E.E., Belchenko G.G., Brunova T.M. Probability analysis of climate change Impact on potential productivity of agricultural ecosystems. Meteorologiya i Gidrologiya (Meteorology and Hydrology)m, 1992, (3): 70–79. (In Russian, abstract in English).
Zhukovsky E.E., Sepp J., Tooming H. Probabilistic forecasts of possible yield. Meteorologija i Gidrologiya (Meteorology and Hydrology), 1990, (1): 95–102. (In Russian with English abstract).
Zhukovsky E.E., Uskov I. B. About the principles of yield programming on the probabilistic basis. In: Modeling and managing of processes in the agroecosystems. Institute of Agrophysics, Leningrad, 1984, pp. 116–126. (In Russian).
Zhukowsky E.E., Sepp J., Tooming H., On the possibility of the yield calculation and forecasting calculation. Vestnik Sel'skokhozjaistvennoi Nauki (Reports of Agricultural Sciences), 1989, (5): 68–79. (In Russian, abstract in English).