Europ. J. Agronomy 32 (2010) 195–204

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

A process-oriented and stochastic simulation model for asparagus spear growth and yield

Jan Graefe[a,*], Adolf Heissner[a], Carmen Feller[a], Peter-Jürgen Paschold[b], Matthias Fink[a], Monika Schreiner[a]

[a] *Leibniz-Institute of Vegetable and Ornamental Crops, Großbeeren and Erfurt, Theodor-Echtermeyer Weg 1, 14979 Großbeeren, Germany*
[b] *Geisenheim Research Center, Von-Lade-Str. 1, 65366 Geisenheim, Germany*

ARTICLE INFO

Article history:
Received 10 June 2009
Received in revised form
13 November 2009
Accepted 20 November 2009

Keywords:
Asparagus
Model
Yield
Physiology

ABSTRACT

To obtain a better understanding of the factors affecting asparagus spear growth and yield, a process-oriented and stochastic model for asparagus (*Asparagus officinalis* L.) grown under soil ridges was developed and tested. This model describes a population of asparagus plants with a binomial distributed bud cluster number per plant. Each bud cluster starts to grow after exposure to an exponential distributed temperature sum. The length growth response of spears, which is mainly dependent on soil temperature and spear length, is affected by the soluble carbohydrate (*CHO*) concentration in the storage root system and the temperature gradient between the spear tip and the rhizome. The spear growth rate is assumed to be normally distributed, while a stochastic dependency to the required temperature sum for bud break is assumed. For each bud cluster, a broadly varied apical dominance relation between successive spears is described by an exponential distributed temperature sum for spear length growth induction. After removal of the dominating spear, the required temperature sum decreases exponentially. The time progression of spear diameter is a function of spear generation number within a bud cluster and the mean temperature during spear growth induction and can be used to derive the spear fresh weight. The change of soluble *CHO* concentrations in the storage root system is derived from maintenance and growth respiration requirements.

Some of the model parameters are derived from independent measurements of spear growth. Regarding the tremendous variability of daily yields, the model performed well in the prediction of daily spear number, diameter and yield over the whole harvest season across two production sites with various soil temperatures induced by different types of ridge covering.

The effects of soluble *CHO* concentration and soil temperature gradient on spear growth rate are regarded as preliminary and should be tested in further experiments. Due to the apical dominance relation between spears, asparagus is subject to endogenous rhythmic growth, which invalidates simple statistical yield forecast approaches. In its current state, our yield forecast model is well suited to test the impact of various plant traits on asparagus yield, and thus to guide early selection in crop improvement projects. Finally, the current model could be used to derive easier to handle yet physiological sound yield models to be useful for field-scale applications.

1. Introduction

Asparagus (*Asparagus officinalis* L.) is an economically important perennial horticultural crop where depending on soil surface management either green or white spears are harvested. In the temperate regions of Europe, the harvest season typically lasts from March to June, and the common usage of plastic covers enables some control of soil temperature and therefore yield. In addition to soil temperature, it is assumed that the concentration of soluble carbohydrates (*CHO*) in the storage root system determines yield. Moreover, it is well known that during harvest the diameter of each successive emerging spear decreases. However, no causal relationships to specific growth processes are known and further causes for within season yield reduction have not been established. *CHO* target concentrations have however been suggested for use at distinct growth stages of asparagus (Wilson et al., 2008). However, there is still no asparagus plant model integrating plant physiological processes with field-scale yield. Therefore, a deeper understanding of asparagus yield physiology could further enhance crop improvement efforts as well as *CHO* resource management.

* Corresponding author. Fax: +49 3370155391.
E-mail address: graefe@igzev.de (J. Graefe).

1161-0301/$ – see front matter
doi:10.1016/j.eja.2009.11.004

The usage of weekly weather forecasts to predict soil temperature (Graefe et al., 2005) together with yield forecast models provides the theoretical basis for management of asparagus grown under plastic covers. From our experience, simple statistical yield models need frequent re-parameterization even if identically treated plants are considered under slightly varying soil temperature histories. Likewise, Liebig and Wiebe (1982) used a dynamic linear regression approach including air temperatures and yields taken on three consecutive days to predict future asparagus yields. Thus with statistical models, reliable current yield data are always required and a degrading performance with increased duration of yield projection is to be expected. Thus, we argue that a plant physiological process-oriented approach that considers all spears from a diverse plant population is more appropriate to account for time-integrated effects of soil temperature on asparagus growth and yield.

This work aims to develop a process-oriented and stochastic simulation model of spear growth and yield for a population of asparagus plants, which provides a new framework for asparagus yield physiology. Some representations of growth processes for which empirical data are not available will be developed from integrated data sets of asparagus yield which will be also used to test the overall validity of the model.

2. Data sets for model calibration and testing

Several data sets were used for model test and development. Some relationships were derived from measurements made on greenhouse grown asparagus. The remaining parameters were estimated from recordings of daily yields from field experiments.

2.1. Measurements of spear elongation growth, fresh mass and diameter

In four consecutive years (2002–2005), two asparagus cultivars (Gijnlim, Grolim) were cultivated at three different ridge temperature treatments ranging from 12 to 26 °C during a greenhouse experiment. The general experimental set-up used is described in Heissner et al. (2006). The dependence of relative spear length growth rate *rsgr* on spear tip temperature T_{sp} and spear length L was parameterized using *in situ* growth data obtained during the years 2002 and 2003 for the cultivar Gijnlim. Daily mean soil temperatures were registered in three depths (5, 20 and 40 cm) and were linear interpolated when linked to specific spears. Spear tip temperature was assumed to be represented by the fastest growing region of spear and according to re-analysed data from Culpepper and Moon (1939), this location is at about 0.2 L back from the spear tip. At the start of spear growth, the distance from spear tip to the spear base, e.g. rhizome, was measured and a thin vertical plastic stick was fixed to the tip. The spear was covered with soil again and daily measurements of spear length were now possible without further disturbing growth. Measured spear lengths were smoothed with a 4th degree polynomial in time from which relative growth rates were derived.

In 2005, spears (22 cm in length) were weighed and diameters measured at 11 cm from spear tip. At weekly intervals, the total carbon (C) and nitrogen (N) content of spears were assessed using a CNS-Analyzer VARIO EL (Elementar Hanau).

2.2. Daily data on spear yield, number and spear size

Two broadly differing data sets were used for model calibration and testing. Experiment I was carried out in 2003 at a farm located 18 km north of Osnabrück (Germany) near the Mittelland canal. The field site is characterized by a humus-rich sandy soil consisting of 4% organic matter, 89% sand and 2.5% clay. At this time, the site had a population density of 18,500 plants ha^{-1} of the cultivar Gijnlim and was planted in 1998 in north–south aligned rows separated by 1.80 m. Hourly soil temperatures were recorded throughout the spear growth zone at 2, 20 and 40 cm below the ridge upper surface. As soil temperature data were unavailable from days 50 to 73, the soil temperature simulation model of Graefe et al. (2005) was used to fill data gaps. For a flat unridged field, asparagus rhizomes were assumed to be located at 20 cm soil depth. Yield monitoring of seven different covering treatments each having a cumulative ridge length of 160 m and a population size of 533 plants was performed. Ridging and covering took place on 15 March, while daily spear harvest lasted from 10 April to 10 June. Harvested spears were washed, sorted and trimmed to a marketable length of 22 cm, and then weighted. Occasionally, the yield data were supplemented with observations on harvested spear numbers and spear size distribution in the size classes (mm) <8, 8–12, 12–16, 16–26 and >26. From given spear size class frequencies, the mean diameter was estimated for daily recordings and aggregated to a mean value over the harvest season.

Experiment II was carried out in 2004 at an experimental field site at the Research Center Geisenheim (Germany). This field site is characterized by a loamy sand consisting of 1.65% organic matter, 51.3% sand and 12.5% clay. Soil temperatures were observed at 5, 20 and 40 cm below the ridge and missing temperature data for days 50–62 were simulated as described above. The field was planted in 1999 with the cultivar Gijnlim, but with a slightly different planting density of 16,660 plants ha^{-1} in 2.0 m separated rows. Daily observations of yield from 50 plants in standard size classes (see Experiment I) were recorded and used to estimate a mean diameter over the harvest period.

3. Model development and simulation procedure

3.1. General model concept

An asparagus population of m plants covered with soil ridges of 40 cm above the rhizome is considered (Fig. 1). Each plant has one to n bud clusters which start to produce spears after initially receiving a defined temperature sum.

After the first spear in a bud cluster starts to grow, the next following spear grows after receiving a further temperature sum sensed at the rhizome depth. Spears elongation growth is a function of soil temperature around the spear tip, the spear length and the *CHO* concentration of the storage root system. When the spear reaches a length of 40 cm, it will be detected and removed by a harvesting person during day time. This removal from the bud cluster reduces the required temperature sum needed for spear growth induction, if the following spear has this sum not yet accumulated. The temperature sum for spear induction is treated as a stochastic variable to account for a probabilistic apical dominance relation between spears within a bud cluster. Therefore, as spear elongation and induction are treated as independent processes, by chance, one, two or even more spears can grow at the same bud cluster and at any one time.

The daily sum of all spears equal to or longer than 40 cm makes up the field-scale yield of the population. To derive the yield per plant in g d^{-1}, a simple relation between the time-dependent mean spear diameter and spear fresh mass is used, while the spear diameter is a function of the cumulative harvested spear number per bud cluster. Using the concept of maintenance and growth respiration, the *CHO* concentration of the storage root system is simulated from the carbohydrate metabolization for spear growth and the maintenance of structural dry matter of the storage root system.