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Specifics of soil temperature under winter oilseed rape canopy

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Abstract: The aim of this study was to evaluate the course of soil temperature under the winter oilseed rape canopy and to determine relationships between soil temperature, air temperature and partly soil moisture. In addition, the aim was to describe the dependence by means of regression equations usable for pests and pathogens prediction, crop development, and yields models. The measurement of soil and near the ground air temperatures was performed at the experimental field Žabčice (South Moravia, the Czech Republic). The course of temperature was determined under or in the winter oilseed rape canopy during spring growth season in the course of four years (2010 – 2012 and 2014). In all years, the standard varieties (Petrol, Sherpa) were grown, in 2014 the semi-dwarf variety PX 104 was added. Automatic soil sensors were positioned at three depths (0.05, 0.10 and 0.20 m) under soil surface, air temperature sensors in 0.05 m above soil surfaces. The course of soil temperature differs significantly between standard (Sherpa and Petrol) and semi-dwarf (PX 104) varieties. Results of the cross correlation analysis showed, that the best interrelationships between air and soil temperature were achieved in 2 hours delay for the soil temperature in 0.05 m, 4 hour delay for 0.10 m and 7 hour delay for 0.20 m for standard varieties. For semi-dwarf variety, this delay reached 6 hour for the soil temperature in 0.05 m, 7 hour delay for 0.10 m and 11 hour for 0.20 m. After the time correction, the determination coefficient (R^2) reached values from 0.67 to 0.95 for 0.05 m, 0.50 to 0.84 for 0.10 m in variety Sherpa during all experimental years. For variety PX 104 this coefficient reached values from 0.51 to 0.72 in 0.05 m depth and from 0.39 to 0.67 in 0.10 m depth in the year 2014. The determination coefficient in the 0.20 m depth was lower for both varieties; its values were from 0.15 to 0.65 in variety Sherpa. In variety PX 104 the values of R^2 from 0.23 to 0.57 were determined. When using multiple regressions with quadratic spacing (modelling of hourly soil temperature based on the hourly near surface air temperature and hourly soil moisture in the 0.10–0.40 m profile), the difference between the measured and modelled soil temperatures in the depth of 0.05 m was –3.92 to 3.99 °C. The regression equation paired with alternative agrometeorological

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instruments enables relatively accurate modelling of soil temperatures ($R^2 = 0.95$).

Key words: soil temperature, canopy, microclimate, sum of effective temperatures

1. Introduction

Soil temperatures influence many processes connected with plant growth and development. On the basis of linear and segmented-non-linear regression models, *Vigil et al. (1997)* estimated the base temperatures for spring canola emergence to be 0.4 and 1.2 °C. *Håkansson et al. (2011)* found out, that under optimum seedbed conditions, thermal time required for 50% germination of rape or white mustard seed about 40 °C days (days above 0 °C) were required for germination and about 8 °C days cm^{-1} for the seedling growth. The soil temperature can also affect the activity of different plant pathogens and pests. From these reasons the soil and near the ground air temperatures course can be necessary for modelling of many processes concerning plant growth and development and prediction of pest and pathogens occurrence. They are not usually at disposal on the crop stand; on the other hand, air temperatures are measured sometimes in the vertical profile of crop canopy (e.g. *Krédl et al., 2012*). *Pokladníková and Rožnovský (2007)* completed gaps in soil temperature databases based on correlation relation between soil temperatures measured at different depths. *Pokladníková and Rožnovský (2006)* investigated long-term winter soil temperature in Pohořelice (South Moravia, the Czech Republic). They interpolated the point data by Surfer 8.0 software for the whole vertical profile (0.05 to 1 m).

There are not many studies evaluating the soil microclimate under the canopy in regard to major field crops grown in Mid-European climate. The shape, dimensions and the geometrical structure of a specific plant species play important roles in the development of the canopy microclimate (*Matejka and Huzulák, 1987*). In our previous work (*Krčmářová et al., 2013*), we evaluated the course of soil temperatures under winter wheat canopy and we determined relationships between soil temperature, air temperature and partly soil moisture. The review of influence of shape, dimension and the geometrical structure of particular crop canopy and relationship between air and soil temperatures within the agroecosystem is given in this publication.

The aim of this study was to evaluate the same phenomenon for the winter oilseed rape as for the above mentioned crop.

2. Material and methods

The measurement was performed at the experimental field station Žabčice (Europe, the Czech Republic, South Moravia). The agrometeorological and pedological conditions of the locality are described by *Krčmářová et al. (2013)*.

The experimental fields were planted with winter oilseed rape variety Petrol in 2010 and 2011 and Sherpa in 2012 and 2014. These varieties have the same morphological character and architecture of stand (i.e. shoot branching, vegetation length, length of plants, and resistance to lodging). In the year 2014 semi-dwarf variety PX 104 was also used. The spacing of the canopy was 0.125 m between rows in population 38 – 43 plants per m^2 in average.

Soil and air temperatures were measured by automatic digital temperature sensors (Dallas semiconductor, DS18B20 type). The near surface air temperature sensors were placed in a radiation shield in 0.05 m level above soil surface in oilseed rape canopy. The soil sensors were placed in the soil under the rape canopy in the depths of 0.05, 0.10, and 0.20 m under soil surface. The data were taken and stored in a data logger at fifteen-minute intervals. The hourly values of air and soil temperatures were obtained as the arithmetic average of the fifteen-minute data. The VIRRIB (Amet, Velké Bílovice) sensors were used for measuring the volumetric soil moisture. The sensors measured hourly soil moisture in 0.20 and 0.40 m depth (horizontally placed sensors) and in 0.10 – 0.40 m depth (vertically placed sensor).

With regard to the technical and time requirement of the exact establishment of leaf area index – LAI (the practise requires a simple and fast method of canopy evaluation), canopy growth and its stages were measured according to the BBCH scale (*Meier, 1997*). The main vegetation period of rape (April to July) was divided into four stages: I. BBCH 30 – 59 (stem elongation to inflorescence emergence), II. BBCH 60 – 69 (flowering), III. BBCH 70 – 79 (development of fruits), IV. BBCH 80 – 89 (ripening).

The range of the near surface air and soil temperatures was plotted as a box plot in the year 2014 for both varieties. The regression analysis was carried out to evaluate interrelationships between soil temperature measured under the winter rape canopy and air temperature in the same canopy. As the course of temperatures in soil can be delayed, cross correlations were computed for this evaluation (software STATISTICA, ver. 12). These models were tested with the coefficient of determination (R^2), as well. For soil temperature modelling based on the near surface air temperature and soil moisture in the 0.10 – 0.40 m profile, multiple regression with quadratic spacing (modelling of hourly soil temperature under canopy based on the hourly near surface air temperature and hourly soil moisture in the 0.10 – 0.40 m profile) was used (software STATISTICA, ver. 12). The average soil temperature (from 15-minute data), per average of experimental years for standard hybrid (hybrid with standard length of plants) and for every developmental period, was delineated in the form of 2D nomogram (software SURFER, ver. 10) by means of the Kriging interpolation method. The same was done individually for variety Sherpa and PX 104 in the year 2014.

3. Results and discussion

Descriptive statistics of the monitoring results covering near the ground air and soil temperatures in or under canopy in three depths (0.05, 0.10 and 0.20 m) for two winter oilseed rape varieties during spring vegetation period of 2014 are displayed in Fig. 1.

Average near ground air temperature in Sherpa variety was 14.85 °C, the range of average soil temperatures lied between 15.49 °C (0.05 m) and 14.57 °C (0.20 m), for PX 104 average near ground air temperature was 13.70 °C and the range of soil temperatures was between 12.95 °C (0.05 m) and 12.53 °C (0.20 m). The maximum differences between these varieties were for depths 0.05 and reached 2.53 °C. This contrast is also evident from the course of sums of effective temperatures above 10 °C (SET_{10}) – see Fig. 2.

Average daily increase (ADI) of air and soil temperatures SET_{10} in particular development stages is given in Table 1. The course of SET_{10} was much slower for PX 104 variety. The maximum difference of ADI of SET_{10}

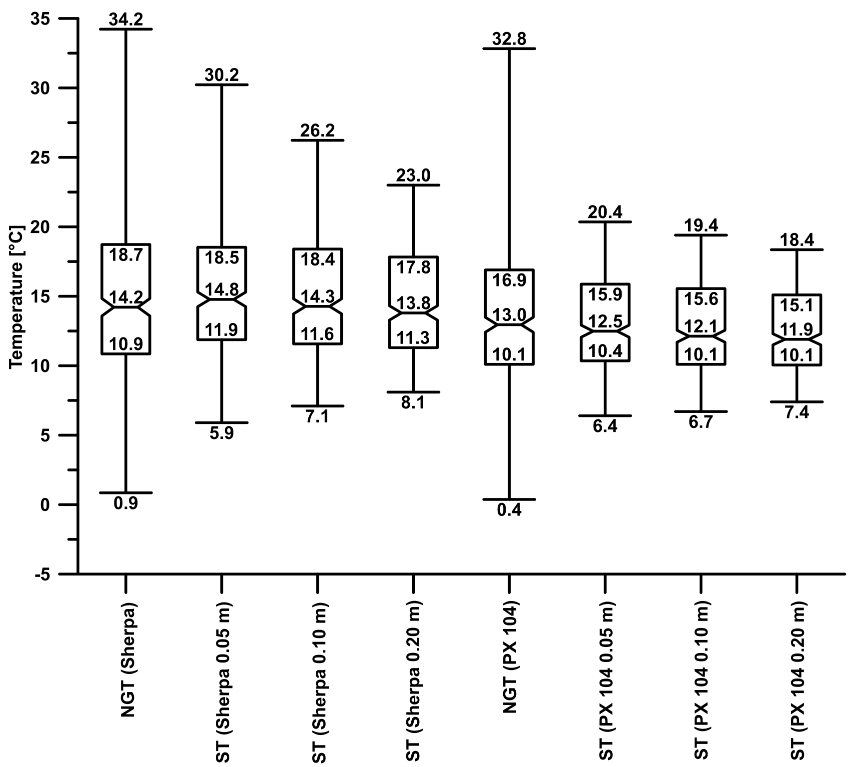

Fig. 1. The range of near ground air temperature and soil temperatures under winter oilseed rape canopy and its descriptive statistics (median, minimum, maximum, first quartile, third quartile). Notes: NGT = near ground air temperature, ST = soil temperature.

was determined in stage II for air (34.34 °C) and in stage IV for soil temperatures (82.37 °C).

The course of air and soil temperature during vegetation period can be also necessary for prediction methods of some oilseed rape pathogens and pests. The appropriate temperature and humidity are inevitable for development of several pathogens stages, too. For example, important pathogen, *Sclerotinia sclerotiorum*, which causes *Sclerotinia* stem rot of rape, develops sexual *ascospores* in fruiting bodies *apothecia* which are formed on fungi mycelium firm bodies, called *sclerocia*. Carpogenic germination of *sclerocia* (*apothecia* formation) occurs from 10 to 25 °C with optimum 20 °C (*Matheron and Porchas, 2005; Mila and Yang, 2008; Wu and Subbarao,*

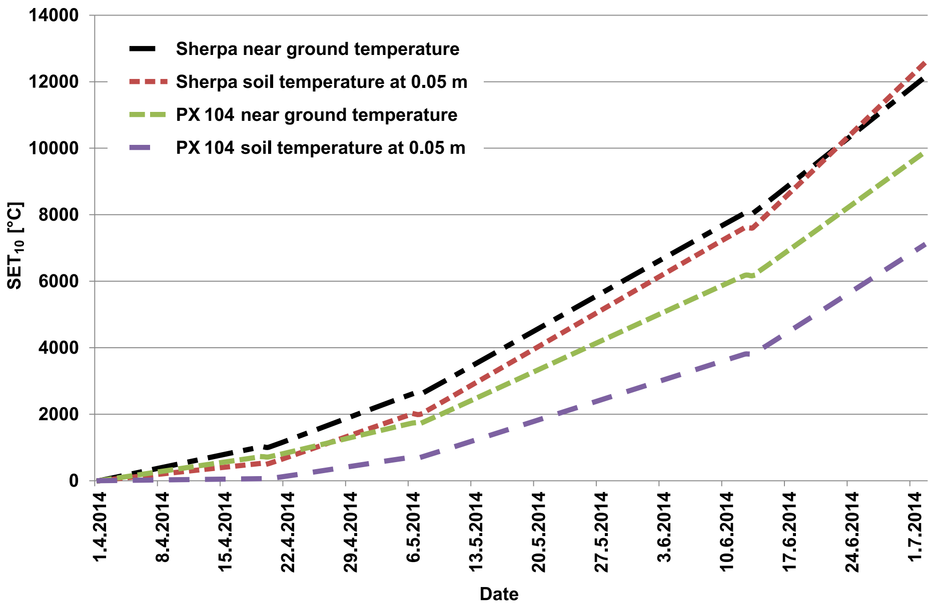

Fig. 2. Dynamics of near ground air temperatures and soil temperatures under winter oilseed rape canopy during main vegetation period expressed as the sum of hourly effective temperatures above 10 °C.

2008). If we use theoretical SET_{10} = 2000 °C in our experiment, it was reached on 7th May 2004 in Sherpa and on 22nd May in PX 104 variety for 0.05 m depth. For the near ground temperatures, this SET_{10} = 2000 °C was determined on 29th April and 9th May, respectively.

As is broadly discussed in *Krčmářová et al. (2013)*, soil temperatures can be influenced by cover of plant canopy and its changes during the year, the spring vegetation period of winter oilseed rape was divided into four stages. Detailed course of soil temperatures and stratification was expressed as 2D nomograms. As can be seen from the Fig. 3, for standard varieties in years 2010 – 2012 and 2014 in average, the highest temperatures were determined in 0.05 m depth between 3 pm to 4 pm in all growing stages. It is evident from Figs. 4 and 5 that the courses of soil temperatures were significantly different under the canopy of particular oilseed rape varieties in 2014. The highest contrast was found for soil temperature in depth 0.05 m in the ripening stage and reached 4.5 °C during daylight. The temperature dis-

Table 1. Average daily increase (ADI) of air and soil temperatures SET_{10} in developmental stages of particular varieties

	Variety	Developmental stage			
		I	II	III	IV
Near ground temperature	Sherpa	53.29	94.14	146.58	203.03
	PX 104	37.83	59.80	119.80	184.01
Soil temperature (0.05 m)	Sherpa	27.29	87.83	151.04	246.06
	PX 104	3.18	38.30	83.52	163.69

tribution in particular depth measured was much more pronounced under Sherpa canopy, the maximum differences were found during daylight and reached from 3 °C in the stage of spring regeneration to 5 °C in ripening stage. On the other hand, these differences were very slight under PX 104 and reached about 1 °C. These phenomena can be elucidated by different plant morphology and canopy architecture of particular oilseed rape variety.

Costes et al. (2013) stressed that the individual plant form, especially the spatial distribution of leaves in space, can determine the within plant microclimate. Also *Calonnec et al. (2013)* and *Tivoli et al. (2013)* in their reviews pointed out the role of canopy architecture on microclimate, especially for wetness, air ventilation and air temperature. These variables can subsequently influence soil temperatures. Different types of soil tillage must be also taken into account (*Sarkar et al., 2007*).

The dependence of hourly soil temperatures under winter oilseed rape canopy on the hourly near surface air temperature was also evaluated. However, this prediction cannot be calculated from air temperatures recorded at the same time. As it was found out by cross correlation analysis, the best interrelationships between these two variables were achieved in 2 hours delay for the soil temperature in 0.05 m, 4 hour delay for 0.10 m and 7 hour delay for 0.20 m for standard varieties (Sherpa and Petrol). For PX 104 this delay reached 6 hour for the soil temperature in 0.05 m, 7 hour delay for 0.10 m and 11 hour for 0.20 m. These delays were slightly different from those determined for wheat by *Krčmářová et al. (2013)*. After the time correction, the determination coefficient reached values from 0.67 to 0.95 for 0.05 m, 0.50 to 0.84 for 0.10 m in standard varieties during all experimental years (Table 2). For variety PX 104 this coefficient reached values from 0.51

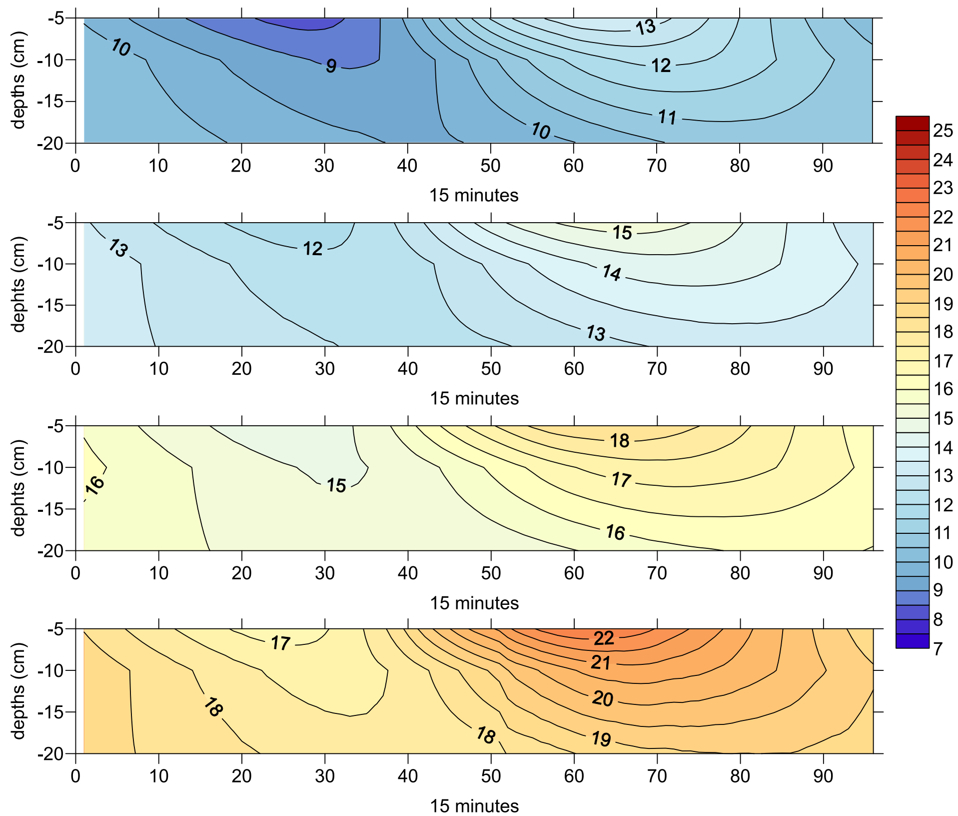

Fig. 3. Dynamics 24-hour course (x-axis, expressed in 15-minute intervals) of soil temperatures (°C) in the 0.05 – 0.20 m soil profile (y-axis, expressed in cm) in years 2010 – 2012 and 2014, standard varieties, from above: 1st, 2nd, 3rd and 4th developmental stage.

to 0.72 in 0.05 m depth and from 0.39 to 0.67 in 0.10 m depth in 2014. The determination coefficient in the 0.20 m depth was lower for both varieties; its values were from 0.15 to 0.65 in variety Sherpa. In variety PX 104, the values of R^2 from 0.23 to 0.57 were determined.

Siebold and von Tiedemann (2012) also found high correlation between air temperatures measured in meteorological station and soil temperatures in depth 0.05 and 0.15 m, respectively, but they used Spearman rank correlation.

Modelling of hourly soil temperature under the oil rape canopy for the

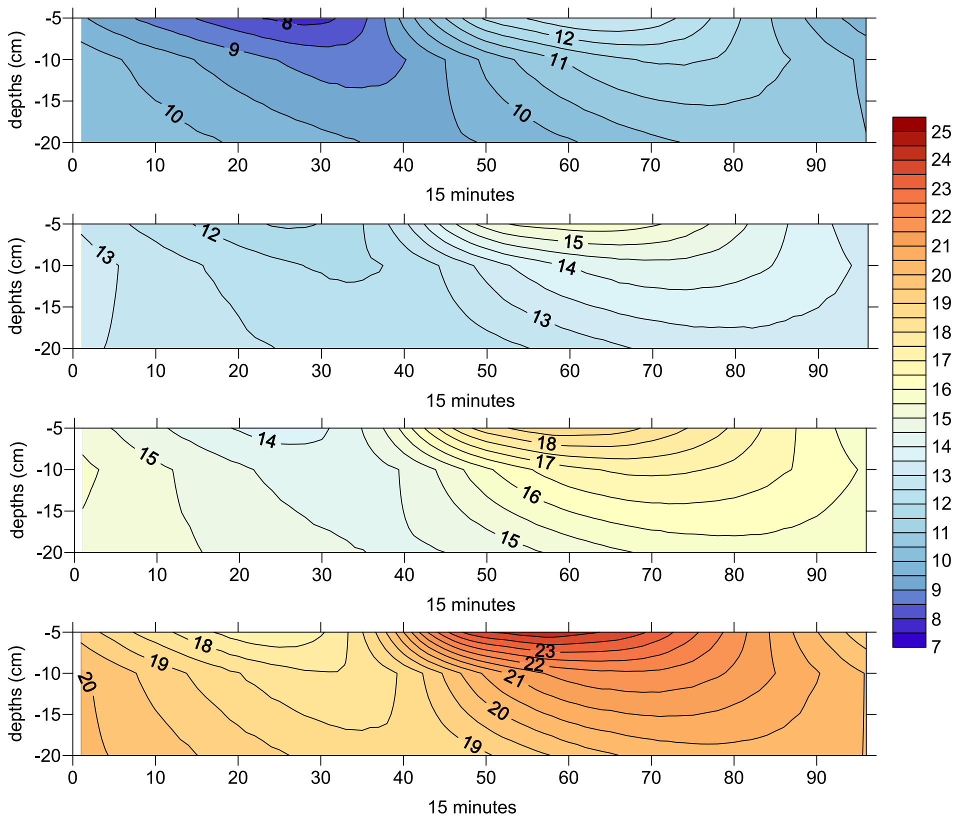

Fig. 4. 24-hour course (x-axis, expressed in 15-minute intervals) of soil temperatures (°C) in the 0.05 – 0.20 m soil profile (y-axis, expressed in cm) in 2014, Sherpa variety, from above: 1st, 2nd, 3rd and 4th developmental stage.

depth of 0.05 m from April to July 2014 (Sherpa variety) was also performed. Correlation among variables was defined by linear regression of the hourly near surface air temperature (i.e. in 0.05 m height above soil surface) in the canopy and the delayed hourly soil temperature under canopy (outcome of cross correlation). The difference among the measured and modelled soil temperatures was –5.85 to 8.50 °C. When using multiple regression with quadratic spacing (modelling of hourly soil temperature in under canopy based on the hourly near surface air temperature and hourly soil moisture in the 0.10–0.40 m profile), the difference between the measured and mod-

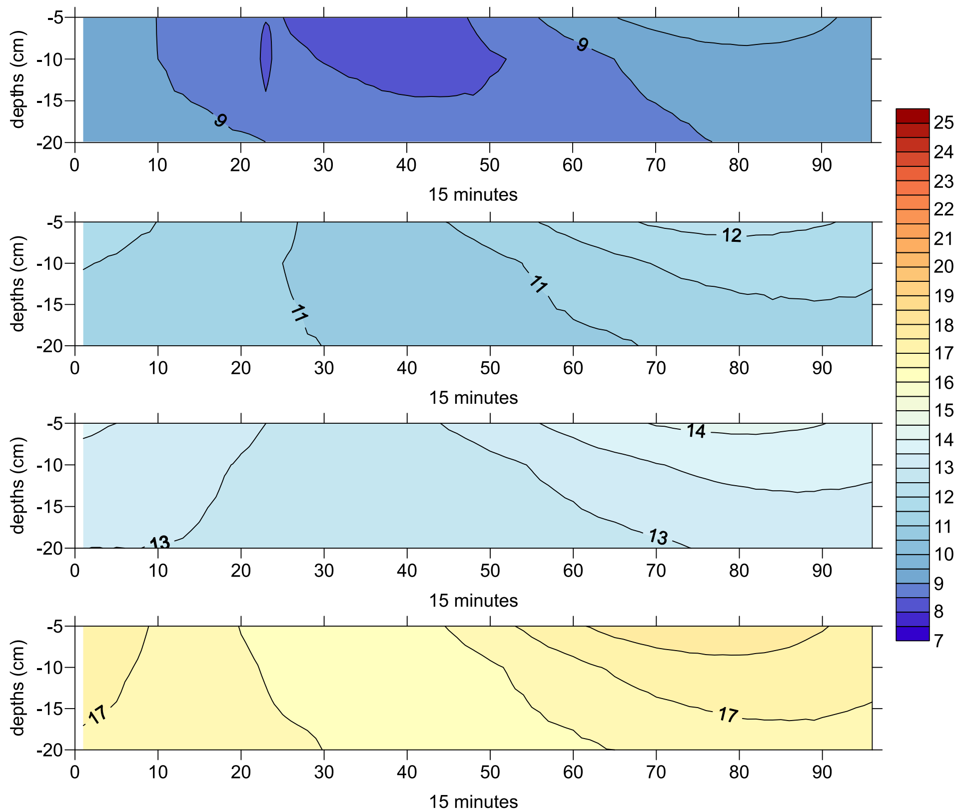

Fig. 5. 24-hour course (x-axis, expressed in 15-minute intervals) of soil temperatures (°C) in the 0.05 – 0.20 m soil profile (y-axis, expressed in cm) in 2014, PX 104 variety, from above: 1st, 2nd, 3rd and 4th developmental stage.

elled soil temperatures in the depth of 0.05 m was –3.92 to 3.99 °C. The regression equation

$$\text{ST (Sherpa 0.05m)} = \\ = 61.7532 + 2.2036\,x - 6.4457\,y - 0.0046\,x^2 - 0.0895\,x\,y + 0.184\,y^2$$

(where x = hourly near surface air temperature in 0.05 m height in °C and y = hourly soil moisture in 0.10 – 0.40 m profile in volume %) enables relatively accurate modelling of soil temperatures (R^2 = 0.95) when compared with using alternative agrometeorological instruments. Nevertheless, the method

Table 2. Regression analysis of dependence of hourly soil temperatures on hourly air temperatures in winter oilseed rape canopy

Year	Variety	Stage	−0.05 m	−0.10 m	−0.20 m
2010	Petrol	I	$y = 0.6424x + 4.3998$	$y = 0.5094x + 5.7863$	$y = 0.3222x + 7.3327$
			$R^2 = 0.8292$	$R^2 = 0.7219$	$R^2 = 0.4762$
		II	$y = 0.7102x + 4.0621$	$y = 0.5964x + 5.5783$	$y = 0.39x + 8.0208$
			$R^2 = 0.8974$	$R^2 = 0.8394$	$R^2 = 0.6484$
		III	$y = 0.6732x + 5.87$	$y = 0.5388x + 7.9729$	$y = 0.3224x + 11.036$
			$R^2 = 0.8959$	$R^2 = 0.8151$	$R^2 = 0.5566$
		IV	$y = 0.7491x + 5.492$	$y = 0.5202x + 9.4133$	$y = 0.2675x + 13.248$
			$R^2 = 0.9492$	$R^2 = 0.8398$	$R^2 = 0.5534$
2011	Petrol	I	$y = 0.5065x + 5.3654$	$y = 0.357x + 6.8761$	$y = 0.19x + 8.3017$
			$R^2 = 0.853$	$R^2 = 0.7314$	$R^2 = 0.4359$
		II	$y = 0.5484x + 5.5437$	$y = 0.426x + 6.944$	$y = 0.2719x + 8.567$
			$R^2 = 0.8855$	$R^2 = 0.789$	$R^2 = 0.5674$
		III	$y = 0.5555x + 7.1332$	$y = 0.4221x + 9.1296$	$y = 0.2653x + 11.277$
			$R^2 = 0.8787$	$R^2 = 0.7512$	$R^2 = 0.4805$
		IV	$y = 0.561x + 7.3578$	$y = 0.4227x + 9.6122$	$y = 0.2234x + 12.782$
			$R^2 = 0.7177$	$R^2 = 0.5073$	$R^2 = 0.1628$
2012	Sherpa	I	$y = 0.4869x + 5.2285$	$y = 0.3674x + 5.9258$	$y = 0.2174x + 6.9566$
			$R^2 = 0.8798$	$R^2 = 0.8047$	$R^2 = 0.557$
		II	$y = 0.393x + 8.6187$	$y = 0.2917x + 9.6736$	$y = 0.1565x + 11.14$
			$R^2 = 0.8329$	$R^2 = 0.743$	$R^2 = 0.5012$
		III	$y = 0.3364x + 10.41$	$y = 0.2331x + 11.625$	$y = 0.1005x + 13.197$
			$R^2 = 0.6694$	$R^2 = 0.5014$	$R^2 = 0.1513$
		IV	$y = 0.3932x + 11.894$	$y = 0.2946x + 13.436$	$y = 0.1682x + 15.335$
			$R^2 = 0.798$	$R^2 = 0.6652$	$R^2 = 0.368$
2014	Sherpa	I	$y = 0.3787x + 6.6993$	$y = 0.2177x + 8.0333$	$y = 0.1101x + 8.9628$
			$R^2 = 0.8514$	$R^2 = 0.7134$	$R^2 = 0.4812$
		II	$y = 0.4434x + 7.6644$	$y = 0.2687x + 9.5759$	$y = 0.1474x + 10.806$
			$R^2 = 0.8654$	$R^2 = 0.6574$	$R^2 = 0.3458$
		III	$y = 0.7257x + 4.8217$	$y = 0.5554x + 6.9424$	$y = 0.4084x + 8.7032$
			$R^2 = 0.8934$	$R^2 = 0.79$	$R^2 = 0.6452$
		IV	$y = 0.6173x + 9.1475$	$y = 0.3569x + 13.389$	$y = 0.1803x + 16.168$
			$R^2 = 0.8857$	$R^2 = 0.7889$	$R^2 = 0.568$

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Table 2. Continued from the previous page

Year	Variety	Stage	−0.05 m	−0.10 m	−0.20 m
2014	PX 104	I	$y = 0.1823x + 7.4192$	$y = 0.1432x + 7.5964$	$y = 0.0932x + 8.1083$
			$R^2 = 0.5857$	$R^2 = 0.4765$	$R^2 = 0.3214$
		II	$y = 0.2376x + 8.7536$	$y = 0.1897x + 9.0369$	$y = 0.1262x + 9.6257$
			$R^2 = 0.5135$	$R^2 = 0.3933$	$R^2 = 0.2255$
		III	$y = 0.4063x + 7.5293$	$y = 0.3675x + 7.8021$	$y = 0.3005x + 8.5543$
			$R^2 = 0.7192$	$R^2 = 0.6665$	$R^2 = 0.5711$
		IV	$y = 0.1483x + 14.36$	$y = 0.1109x + 14.783$	$y = 0.0584x + 15.519$
			$R^2 = 0.6341$	$R^2 = 0.5119$	$R^2 = 0.2765$

would be widely applicable when using the data from various meteorological and pedological conditions. *Kätterer and Andrén (2009)* developed different model based on air near ground temperature and LAI of oilseed rape plants, which predicted in 95% of simulated daily soil temperatures differ by less 2.8 °C from measurement. Our results give possibilities to make more accurate growth models and prediction methods of some pathogens or pests occurrence.

4. Conclusion

The impact of year, variety, winter oilseed rape canopy structure and the growth stage on the soil temperature in various depths was determined. Detailed course of soil temperatures and their stratification in the soil profile for particular vegetation periods was expressed by 2D nomograms. The time delay of soil temperatures under rape canopy in comparison with air temperatures was quantified by cross correlations. The regression between soil temperature, air temperature and partly soil moisture in the winter oilseed rape stand was established. These findings can be used in making more accurate prediction models of pathogens and pest occurrence on winter rape, in crop and yield development, soil evaporation, soil heat fluxes etc.

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