PREDICTING FIELD HYDROLOGY IN NO-TILL FIELD CONDITIONS USING DRAINMOD

PREVISION DE L'HYDROLOGIE DU CHAMP DANS LES CONDITIONS DE NON LABOURAGE UTILISANT DRAINMOD

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ABSTRACT

In the past 20 years no-till farming have gained interest for their potential to increase available soil water, improve soil quality, and improve the global environment. Collecting long-term hydrological data for a range of climatic condition is not only an expensive and time consuming process, but it is also quite difficult. Incorporation of real-time field data with a validated hydrological and water quality simulation model is economical and time-efficient. Although models have been extensively used in different parts of the world to evaluate the hydrology of artificially drained lands, less is known in the no-till fields. The model called DRAINMOD is gaining more attention because of its simplicity, easy-of-use, and versatility in considering various water-table management practices. DRAINMOD 6.0 was assessed for the tile drainage in no-till filed of Truro, Nova Scotia. The model was calibrated using drain outflow data over the 2003-2004 and validated by drain outflow over the year of 2005-2007. The results of the model had a good degree of accuracy. The R^2 and RRMSE for daily/ monthly calibration period were 0.73/0.92 and 0.44 mm/2.2 mm, respectively. The R^2, RRMSE and E for monthly drain outflows were 0.79, 2.5 and 0.67, respectively, during the validation period. The results demonstrated that, DRAINMOD is able to simulate the hydrology of no-till fields over the entire year, including the cold months.

Key words: *No-till, DRAINMOD, Hydrology, Drain out flow, Model validation.*

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RESUME ET CONCLUSIONS

L'agriculture de conservation, en particulier non-labour, a été prouvée à fournir une agriculture durable dans de nombreux environnements agricoles pratiquement partout dans le monde. Au cours des 20 dernières années sans labour méthode a suscité un intérêt pour son potentiel d'augmenter l'eau disponible du sol, améliorer la qualité des sols, et améliorer l'environnement mondial. En vertu de ces pratiques, un résidu de 30% ou plus la couverture de la récolte précédente est laissée sur la surface du sol. Bien que de travail minimum peut réduire les pertes d'eau et certains polluants à la surface de drainage, cette pratique peut augmenter l'infiltration dans le sol et le lessivage dans les eaux souterraines.

La proportion de terres préparées pour l'ensemencement sans labour a augmenté de 7% à 46% de 1991 à 2006 au Canada. En Nouvelle-Écosse, l'utilisation du semis direct est passé de 4% de la superficie totale préparée pour l'ensemencement en 1991 à 14% en 2006. Aussi il ya un excédent de précipitations à certaines périodes de l'année dans cette région. Par conséquent, le drainage artificiel sous forme de sous-sol drains horizontaux est souvent nécessaire de fournir de meilleures conditions pour l'utilisation de machines agricoles.

La collecte à long terme des données hydrologiques pour une gamme de conditions climatiques n'est pas seulement un processus long et coûteux, mais il est aussi assez difficile. Incorporation des données de terrain en temps réel avec un modèle validé de la qualité hydrologique et la simulation est économique en temps et en efficacité. Bien que les modèles ont été utilisés dans différentes parties du monde afin d'évaluer l'hydrologie des terres drainées artificiellement, il n'a pas été largement appliquée dans un no-till condition. DRAINMOD est un modèle de gestion polyvalence de la nappe phréatique qui a été appliquée avec succès pour simuler les écoulements d'eau et les conditions d'humidité du sol en de nombreux endroits d'Amérique du Nord. Par conséquent, l'objectif de cette étude était d'évaluer la capacité des DRAINMOD 6.0 pour simuler les sorties de drain souterrain sous le No-till dans un état climat froid. Un système de drainage souterrain a été installé dans un champ de six hectares à Truro, en Nouvelle-Écosse, Canada en 1995 (45^o 22^o N, 63^o 16^o W). Le système a déjà été utilisé pour comparer les effets du fumier de volaille composté et du fumier frais sur la qualité de l'eau. La parcelle a été divisée en 10 parcelles (36 m × 72 m) à chaque parcelle isolée par un tampon hydrologique drains. Ces parcelles se compose de cinq labour conventionnel (CT) et cinq de culture sans labour (ZT) systèmes. Depuis la parcelle 6 (no-till parcelle) a eu un ensemble de données complet, le flux de données de drainage pour ce terrain a été utilisé pour évaluer le modèle. conduits de drainage perforés (100 mm de diamètre) sont situées à une profondeur moyenne de 80 cm à 12 m espacement.

Le modèle a été calibré en utilisant des sorties de drain, sur la période 2003-2004 et validés par des sorties de drain, sur l'année 2005-2007. Les résultats du modèle a eu un bon degré de précision. Le R^2 et RREQM pour la période de calibrage journalier / mensuel ont été 0.73/0.92 et 0.44 mm/2.2 mm, respectivement. Le R^2, RREQM et E pour les sorties de drains mois sont de 0.79, 2.5 et 0.67, respectivement, au cours de la période de validation. Les résultats ont démontré que, DRAINMOD est capable de simuler l'hydrologie des champs non labourés sur toute l'année, y compris les mois d'hiver.

Mots clés : *Non labourage, DRAINMOD, Hydrologie, drain restitué, validation du modèle.*

(Traduction française telle que fournie par les auteurs)

1. INTRODUCTION

Conservation agriculture, especially no-tillage helps sustainable farming in many agricultural environments virtually around the world (Baker et al., 2006). In the past 20 years no-till method has gained interest for its potential to increase available soil water, improve soil quality, and improve the global environment. Under such practices, a 30% or greater residue cover from the previous crop is left on the soil surface (Environment Canada, 2004). Although minimum-tillage may reduce water losses and some pollutants to surface drainage, this practice may increase infiltration into the soil and leaching to groundwater (Environment Canada, 2004; USEPA, 2005).

The proportion of land prepared for seeding using no-till practices increased from 7% to 46% from 1991 to 2006 in Canada. In Nova Scotia, the use of no-till increased from 4% of the total area prepared for seeding in 1991 to 14% in 2006 (Hoffman, 2008). Also there is a surplus of precipitation at certain times of the year in this region. Therefore, artificial drainage in the form of horizontal subsurface drains is often required to provide better conditions for farm machinery operation (Hoffman, 2008).

Collecting long-term hydrological data for a range of climatic condition is expensive, time consuming and difficult. Although models have been used in different parts of the world to evaluate the hydrology of artificially drained lands, it has not been applied extensively in no-till condition. DRAINMOD is a versatile water-table management model (Kandil et al., 1995; Skaggs, 2008) that has been successfully applied to simulate water flows and soil moisture conditions in many locations of North America (Dayyani et al., 2010; Luo et al., 2000). The goal of this study was to evaluate the capacity of DRAINMOD 6.0 to simulate subsurface drain outflows under no-till in a cold climate.

2. MATERIALS AND METHODS

2.1 Site description

A subsurface drainage system was installed in a six ha field in Truro, Nova Scotia, Canada in 1995 (45° 22° N, 63° 16° W). The system was previously used to compare the effects of composted poultry manure and fresh manure on water quality (Thiagarajan et al., 2007). The plot was divided into 10 plots (36 m × 72 m) with each plot isolated hydrologically by buffer drains. These plots consist of five conventional tillage (CT) and five zero tillage (ZT) systems. The plot layout, drainage and treatment details are illustrated in Figure 1. Since the plot 6 (no-till plot) had a complete dataset, the drainage flow data for this plot was used to evaluate the model. Perforated drainage conduits (100 mm in diameter) are located at an average depth of 80 cm with 12 m spacing. The drainage system information is given in Table 1.

Soil in plot 6 is imperfectly drained and is classified as the Pagwash 52. Soils of Pagwash group have developed in coarse loamy till derived from sandstone of the carboniferous period. Pagwash 52 soils have 50 to 80 cm of friable, coarse loamy solum over firm, coarse loamy, lower soil material (Webb et al., 1991). Soil water characteristic of this soil were obtained using the standard pressure plate method. Saturated conductivities were determined by adjusting the values from the core method with the field effective soil hydraulic conductivities (Madani and Brenton, 1995; Madani et al., 1997).

2.2 Data measurements

Hourly precipitation, air temperature and subsurface drain outflow were measured at the site. A weather station was installed approximately 90 m from the edge of the experimental site. This weather station consisted of a tipping bucket rain gauge connected to a datalogger (CR10X, Campbell Scientific, Edmonton, AB) which was used to record the rainfall at experimental sites. Hourly drain outflow rates were recorded continuously using calibrated tipping buckets connected to the dataloggers (CR10X, Campbell Scientific, Edmonton, EB and Zeno 3200, Coastal Environmental Systems, Seattle, WA).

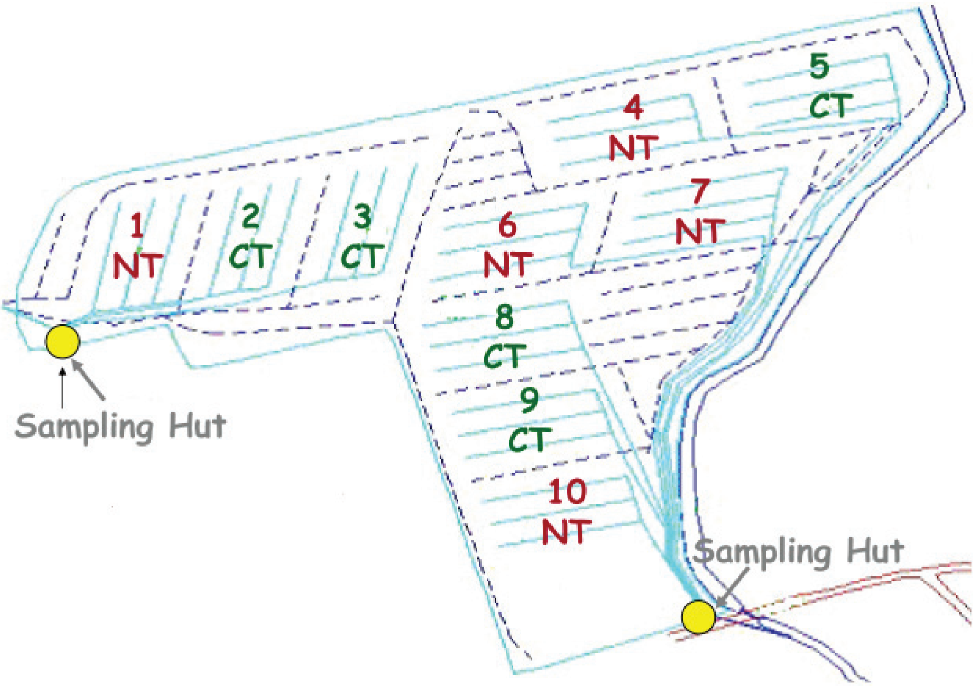

Fig. 1. Experimental field plot layout (CT: Conventional tillage, ZT: zero tillage)

Table 1. DRAINMOD input parameters

Parameters	Values
Drainage System	
Drain depth (cm)	80
Drain spacing (cm)	1200
Effective radius of drain (cm)	5
Actual distance to impermeable layer (cm)	100
Drainage coefficient (cm d^{-1})	2
Maximum surface storage (cm)	0.5
Kirkham's depth for flow to drains (cm)	0.5
Lateral saturated hydraulic conductivity of 4 layers (cm h^{-1})	11, 4.75, 5.3, 2.2
Soil Temperature	
Thermal conductivity function coefficient (W $m^{-1o}C^{-1}$)	a=0.55, b=1.96
Phase lag for daily air temperature sine wave (h)	9
Rain/snow dividing temperature (^oC)	-2
Snowmelt base temperature (^oC)	-3
Snowmelt coefficient (mm ^oC d^{-1})	2
Critical ice content (cm^3 cm^3)	0.2
ET monthly factors	
Jun.= 1.1, Feb.= 1.15, Mar.= 1.1, Apr.= 1.1, May= 1.1, June= 0.9,	
July = 0.4, Agu.= 0.5, Sep.= 0.7, Oct.= 0.7, Nov.= 0.9, Dec.= 1.1	

2.3 Model Inputs

DRAINMOD inputs include climate data (daily max/min temperature and hourly precipitation), soil properties, drainage volume-water table depth relationship, upward flux, infiltration parameters, crop parameters, and drainage system parameters (Skaggs, 1980; Workman and Skaggs, 1994). The drainage volume, upward flux and infiltration parameters were calculated by an internal DRINMOD subroutine, which used the soil water properties of each layer of the soil to produce values of volume drained for water table positions ranging from the surface to the bottom of the soil profile (Skaggs, 1980).

Climate data include hourly rainfall and daily max/min temperature were collected at the Truro station and used in DRAINMOD model. Potential evapotranspiration was calculated during simulation using the Thornthwaite equation.

In order to reflect the freezing and thawing phenomenon, additional inputs were required (Luo et al., 2000). These include the two constants relating soil thermal conductivity to soil water content, the rain and snow dividing temperature, the snow melt base temperature and degree-day coefficient for snowmelt, the critical ice content above which infiltration stops, the initial soil temperature distribution and a base temperature as the lower boundary condition, the phase lag for daily air temperature sine wave, the initial snow depth, and soil freezing characteristics which indicate the relationship between unfrozen water content and soil temperature (Table 1).

3. RESULTS AND DISCUSSION

The objective of the calibration process was to minimize difference between measured and simulated data. DRAINMOD was manually calibrated using of daily drain outflows in 2003-2004, while daily drain outflow data for 2005-2007 were used for model validation. The simulated daily and monthly drain outflows were compared with observed data for both model calibration and validation. Daily and monthly observed and simulated drain outflows in subsurface drains were compared by statistical parameters including: average absolute deviation (AAD), relative root mean square error (RRMER), coefficient of determination (R^2) and coefficient of efficiency (E).

The AAD value shows the overall magnitude of deviation of simulated values from observed ones and is given by Janssen and Heuberger (1995):

$$AAD = \frac{\sum_{i=1}^{n} |O_i - P_i|}{n} \quad (1)$$

where O_i is the *i*th observed values, P_i is the *i*th predict value, for a total number of events “n”. Relative root mean square error is suggested by El-Sadek et al. (2001).

$$RRMSE = \frac{\sqrt{\sum (O_i - P_i)^2}}{O_{avg}} \quad (2)$$

where O_{avg} is the mean observed value.

R^2 is also used to compare observed and predicted values (El-Sadek et al., 2001; Fernandez et al., 2006) and it is expressed as:

$$R^2 = \frac{\left(\sum_{i=1}^{n}(O_i - O_{avg})(P_i - P_{avg})\right)^2}{\sum_{i=1}^{n}(O_i - O_{avg})^2 \sum_{i=1}^{n}(P_i - P_{avg})^2} \quad (3)$$

where P_{avg} is the mean predicted value.

The coefficient of efficiency, E has been widely used to evaluate the performance of hydrologic models. Nash and Sutcliffe (1970) defined the coefficient of efficiency as:

$$E = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - O_{avg})^2} \tag{4}$$

Values of E between 0.5 and 1.0 are considered acceptable (Wang et al., 2006a).

3.1 Model calibration

DRAINMOD was manually calibrated by comparing observed and simulated drainage outflows. During the calibration process, to obtain the optimal agreement between the predicted and observed system variables, the model input parameters were changed. Calibration parameters were selected based on previously cited literature and adjusted on a trial-and-error basis using daily and monthly drain flow. The results for both daily and monthly drain outflows were plotted and visually examined for a match between the observed and predicted values. This evaluation looked at the proximity between the simulated and observed values and the timing of peak flows. For the best simulation thus determined, in term of daily and monthly drain outflows, further assessment was made by computing various statistical parameters.

The calibration parameters consisted of soil hydraulic parameters (saturated hydraulic conductivity, lateral saturated hydraulic conductivity (cm h^{-1}) and factor α (cm^{-1})), monthly ET adjustment factors, drainage coefficient, and maximum surface storage (Singh et al., 2006; He et al., 2002; Wang et al., 2006b). The initial lateral saturated hydraulic conductivity values for different soil layers were set at twice the vertical saturated hydraulic conductivity as suggested by Skaggs (1980). The calibration parameters that provided the best overall results are given in Table 1.

DRAINMOD requires inputs for the initial soil temperature profile, upper boundary, and a base temperature as the lower boundary condition. The appropriate value for the upper boundary condition is the soil surface temperature. Since the long record of measured soil surface temperatures is not usually available for most applications, air temperature was used instead (Luo et al., 2000). The lower boundary was assumed to be a constant soil temperature, which can be approximated as the long–term average air temperature (Penrod et al., 1958).

Simulated and observed subsurface flows for daily and monthly hydrograph during the calibration period (2002-2003) are shown in Figure 2 and 3. Although in some events, spatially in years of 2003, peak flows were slightly over- or underestimated, DRAINMOD accurately simulated the peak drainage flows as well as the pattern of drain outflows. Figure 3 shows that DRAINMOD simulations closely matched with observed monthly drain outflow. In most months of calibration year, the difference between the simulated and observed monthly outflow was lower than 1 cm $month^{-1}$ (Figure 3). This indicated that the model was calibrated very well.

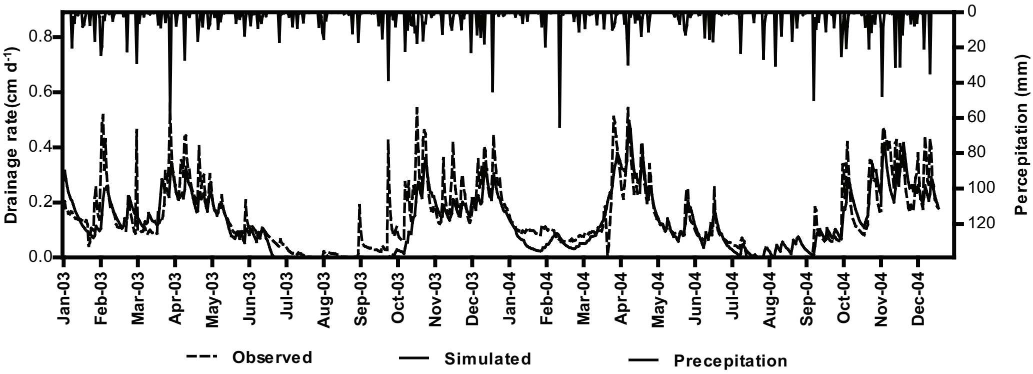

Fig. 2. Simulated vs. observed daily drain outflow for calibration years

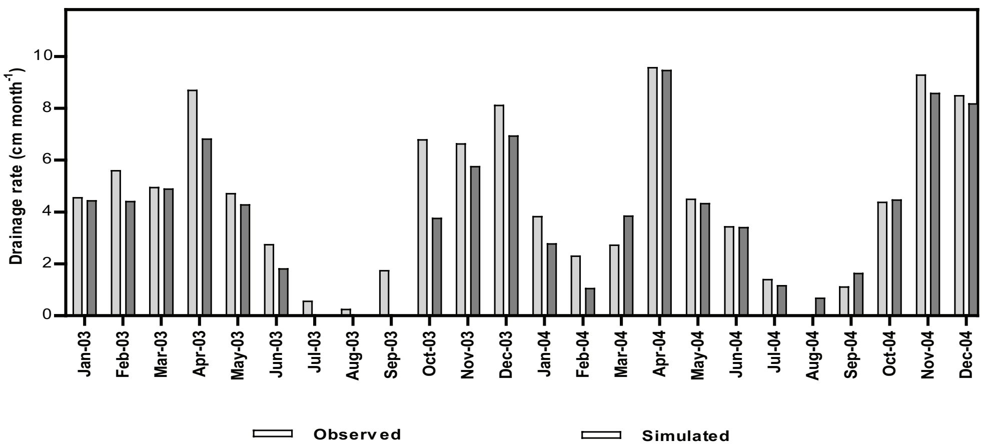

Fig. 3. Simulated vs. observed monthly drain outflow for calibration years

The statistical indices calculated from the simulated and observed daily and monthly outflow for calibration period are given in Table 2. Values of AAD and RRMSE for daily drain outflows were 0.42 mm and 0.44 mm, respectively. Furthermore, the R^2 (0.73) and E (0.71) values showed a good agreement between observed and simulated daily drain outflows (Table 2). Luo et al. (2001) calculated AAD values for daily drainage rate 0.7 mm to 0.9 mm for an experimental site in Nova Scotia. Also Dayyani et al., (2010) in Quebec (cold climate) calculated the AAD values for daily drain outflow 0.29 mm.

Table 2. Statistical comparison between observed and simulated drainage outflow during the calibration period

Statistical Parameter	Calibration Period
Daily drain outflow	2003-2004
AAD(mm)	0.42
RRMSE(mm)	4.4
R^2	0.73
E	0.71
Monthly drain outflow	2003-2004
AAD(mm)	7.13
RRMSE(mm)	2.2
R^2	0.92
E	0.89

Figure 3 shows a close agreement between the predicted and observed monthly drainage flow for the calibration years. The RRMSE and AAD for monthly drain outflow during the calibration period were 2.2 mm and 7.13 mm, respectively. Furthermore the monthly values of E and R^2 for this period were 0.89 and 0.92, respectively. These results confirmed that DRAINMOD performed well in the prediction drain outflow during the calibration year. Wang et al., (2006a) calculated values of R^2 ranging from 0.7 to 0.84 for monthly drain outflow for Nova Scotia.

3.2 Model validation

Drain outflow data of 2005-2007 were used to validate DRAINMOD model. During the calibration period, the input parameters of model were adjusted to obtain the optimal agreement between the predicted and observed drain outflows. To validate the calibrated model, the daily and monthly predicted and observed drain outflow during the years of 2005-2007 were compared. These are shown in Figure 4 and 5.

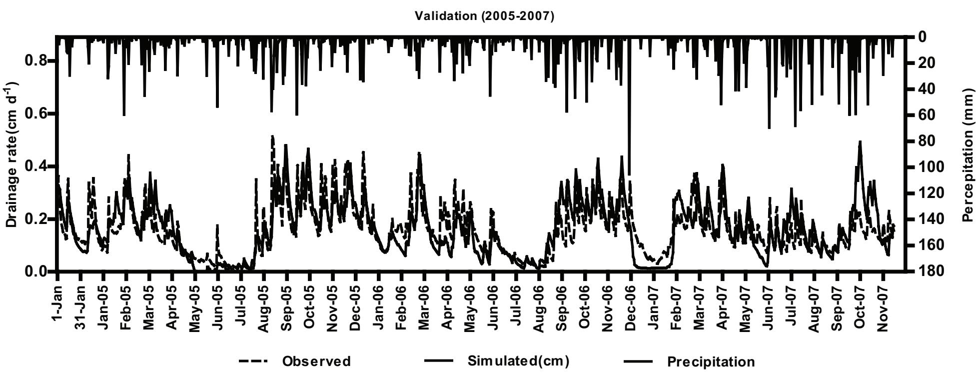

Fig. 4. Simulated vs. observed monthly drain outflow for calibration tion years

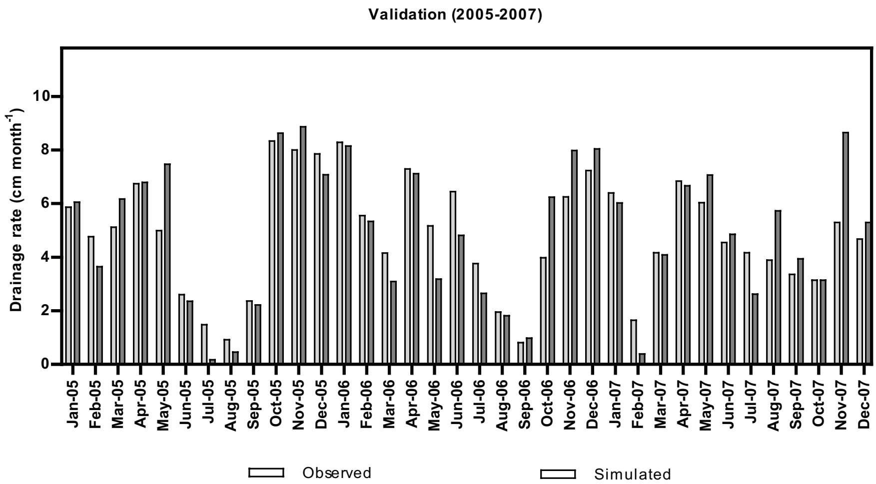

Fig. 5. Simulated vs. observed monthly drain outflow for validation years

Although there are slight under and over estimation for the certain events, most simulated drain outflow peaks matched corresponding observed values well, especially in the cold months (Figure 4 and 5). Luo et al., (2001) showed that during the fall events in Truro, DRAINMOD 5.1 over estimated the drainage flow. They demonstrated that this could have been caused by under-estimating ET during the growing season, resulting in less predicted storage in the profile and more drainage than observed.

The AAD and RRMSE for daily validation period were 0.49 mm and 4 mm, respectively, showing that the results of the model are reasonable (Table 3). Furthermore, R^2 (0.63) and E (0.51) parameters for daily values were considered as good (Wang et al., 2006a). The cumulative drain outflow over the validation years was 2% higher than the observed drain outflow. The overall RRMSE in predicted monthly drain outflow was 2.5 mm (Table 4). The monthly values of R^2 and E were 0.79 and 0.67, respectively, showing a close agreement between predicted and observed drain outflows during the validation years (Table 4). The results also show that DRAINMOD is quite able to predict the peak daily flow during the both of warm and cold seasons very well under no-till systems.

Table 3. Statistical comparison between daily observed and simulated drainage outflow during the validation period

Statistical Parameter	Validation Period
Daily drain outflow	2005-2007
AAD(mm)	0.49
RRMSE(mm)	4
R^2	0.63
E	0.51

Table 4. Statistical comparison between monthly observed and simulated drainage outflow during the validation period

Statistical Parameter	Validation Period
Monthly drain outflow	2005-2007
AAD(mm)	8.78
RRMSE(mm)	2.5
R^2	0.79
E	0.67

4. CONCLUSIONS

DRAINMOD 6.0, a field scale water balance simulation model, was employed to predict drain outflow from a no-till agricultural field in Truro, Nova Scotia, Canada. This version of model includes the algorithms to simulate of the cold conditions. The model predicted daily and monthly drain outflows were good agreement with the measured values. The R^2, RRMSE and E for the daily/monthly calibration period (2003-2004) were 0.73/0.92, 4.4/2.2, and 0.71/0.89, respectively. The model gave good results for drain outflow in cold months and also it could simulated the patterns of daily drain outflows and the peak flows in all seasons. The R^2, RRMSE, and E for the monthly validation period (2005-2007) were 0.79, 2.5, and 0.67, respectively. These values are indicated of an acceptable model performance in a cold region for no-till agricultural field of North America.

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