https://doi.org/10.17221/49/2017-RAE

Optimization of tillage and sowing operations using discrete event simulation

Armaghan Kosari Moghaddam, Hassan Sadrnia*, Hassan Aghel, Mohammad Bannayan

Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, Iran

**Corresponding author: hassan.sadrnia@um.ac.ir*

Abstract

Kosari Moghaddam A., Sadrnia H., Aghel H., Mohammad B. (2018): Optimization of tillage and sowing operations using discrete event simulation. Res. Agr. Eng., 64: 187–194.

A simulation model was developed for secondary tillage and sowing operations in autumn, using discrete event simulation technique in Arena® simulation software (Version 14). Eight machinery sets were evaluated on a 50-hectare farm. Total costs including fixed-costs, variable costs and timeliness costs were calculated for each machinery set. Timeliness costs were estimated for 21-years period on daily basis (Daily Work method) and compared with another method (Average Work method) based on the equation proposed by ASAE Standards, EP 496.3FEB2006. The Inputs of the model were machinery sets, field size, machines performances and daily soil workability state. The optimization criteria were the lowest costs and lowest standard deviation in daily work method plus the lowest costs based on average work method. The validity of the model was evaluated by comparing the output of the model with field observed data collected from various farms. Results revealed that there was no significant difference ($P > 0.01$) between the observed and predicted finish day.

Keywords: discrete event simulation; modeling, sowing; tillage, timeliness costs

The costs of ownership and operating of farm machinery were almost the largest part of production costs. Therefore, development or selection of the optimal machinery systems could help to reduce the costs. In addition, providing timely field operations will help to optimize the yield and its quality (Rotz, Harrigan 2005). A logical selection of farm machinery consists of four segments included system power requirement, tractor-implement combination, field-machine matching and cost analysis (Ogunlowo 1997). One of the most important factors in machinery selection procedure is cost analysis. So we have to define a criterion for choosing an optimum machinery set through economic aspect. For a given farm, the "appropriate" machinery set in economic terms would be the "least-cost" set when specific machinery, labor and timeliness costs are considered" (de Toro, Hansson 2004).

Many studies were performed about the selection of optimum machinery sets and majority of them have used mathematical optimization modeling. Mathematical models (Camarena et al. 2003; Søgaard, Sørensen 2004) usually have been used for specific crops, crop rotation and farm machines. These models have specific limits and target function for minimization of costs or maximization of benefits. Another programs (Al-Hamed, Al-Janobi 2001; Sahu, Raheman 2007; Dash, Sirohi 2008) which are based on computer programming languages and contain databases that could be performed for different crops or machinery sets and other conditions. These types of modeling approaches are more user-friendly but most of the above-mentioned researches were not considered timeliness costs or used conventional methods based on average work methods. Other types of

https://doi.org/10.17221/49/2017-RAE

these programs are based on discrete event simulation technique. This modeling technique provides simulation of daily field operations on a farm considering available resources (machinery, labour), constraints (e.g. soil workability) and management criteria. This technique may also allow estimation of timeliness costs and their variations with better accuracy than those methods working with single values of workdays (de Toro, Hansson 2004).

There are a lot of studies that have used simulation modeling for agricultural production costs management and optimizing the selection procedure of farm machinery however there are a few studies that have considered timeliness costs. Most of approaches and tools that have determined timeliness costs, used methods based on international or local standards and only reported these costs based on average of various years. The aim of this study was to implement the discrete event simulation method for determining timeliness costs based on daily basis and comparing it with conventional method (Average work method) based on ASAE standards.

MATERIAL AND METHODS

A simulation model for farm machinery operations was developed using discrete event simulation technique. Inputs of the model are soil workability state, farm size, machinery sets and field capacity of each machine. The general trend of simulation processes similar to de Toro and Hansson (2004) is outlined in Fig. 1.

Estimation of working days. A soil moisture model was developed (Kosari Moghaddam 2014) and was run using 21-years (1992–2012) weather data from a meteorological station of Mashhad and soil characteristics of Research Station of Ferdowsi University of Mashhad (36°15'N/59°36'E) (Koocheki et al. 2011). The soil texture of this farm was loam type and field capacity was estimated 210 mm, similar to other loam soils in this location (Bannayan et al. 2011). Workdays were estimated for autumn using two workability criteria namely daily soil moisture less or equal to 85% field capacity (de Toro, Hansson 2004) and daily precipita-

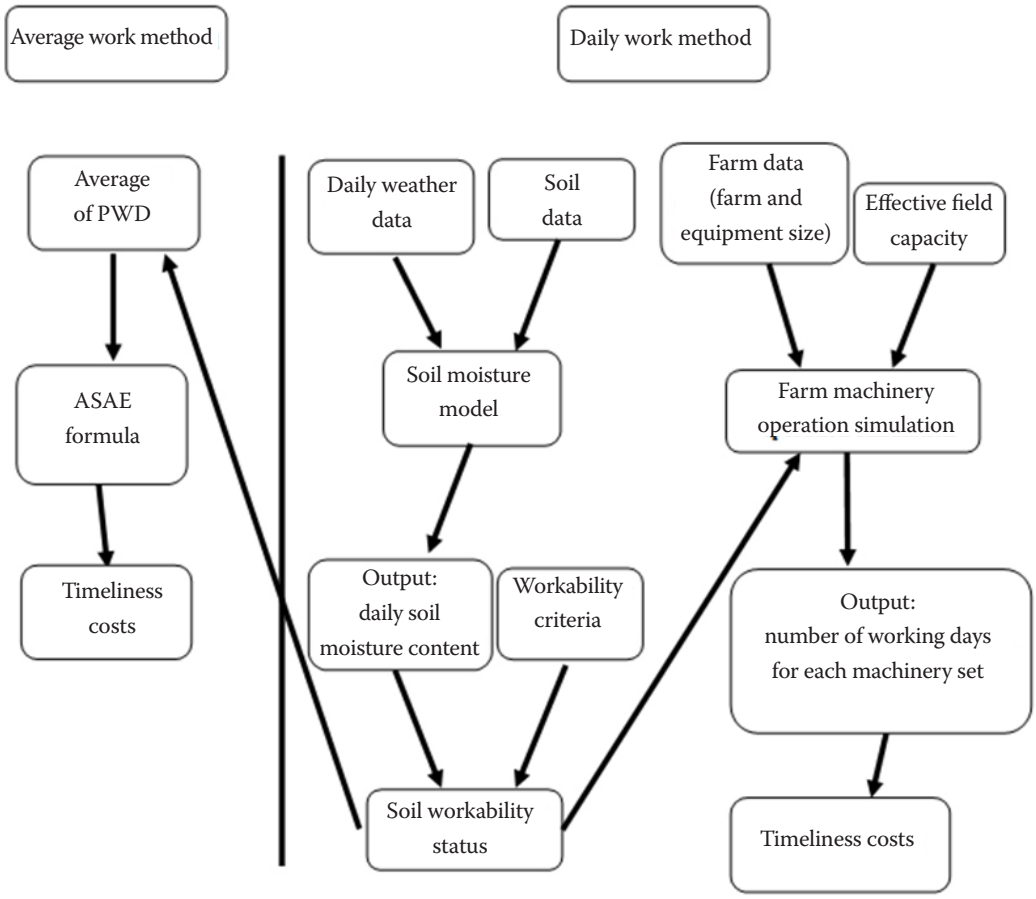

Fig. 1. Schematic representation of two methods (daily work method and average work method) for determination of timeliness costs (de Toro, Hansson 2004)

https://doi.org/10.17221/49/2017-RAE

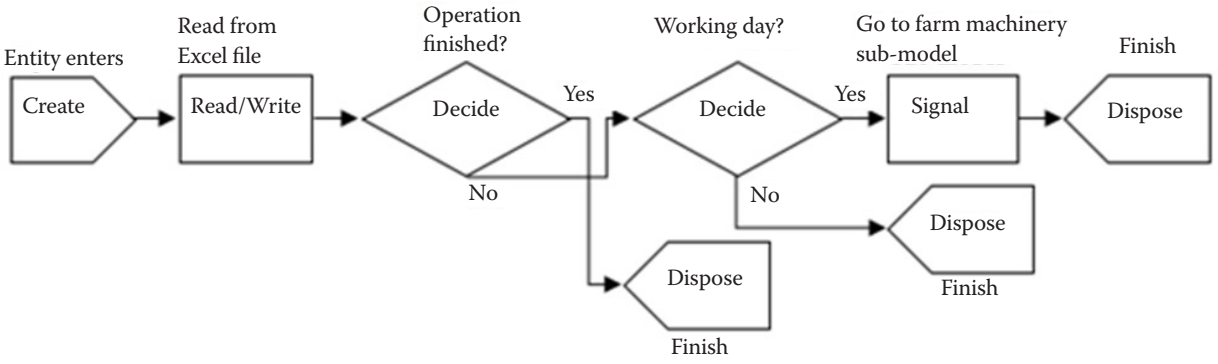

Fig. 2. A simplified sketch of workdays sub-model

tion less than 4 mm (local surveys). The output of this model was used as input of daily work method and probability of workdays in complete periods were used as input of average work method.

Simulation of farm machinery operations. Farm machinery operations were simulated using discrete event simulation technique in Arena® simulation software (Rockwell Automation, Version 14, Milwaukee, USA) with two following sub-models namely workdays and farm machinery operation. The computational experiments were performed on an Intel Pentium T4400 CPU2.2 GHz workstation. In workdays sub-model, a "day" that should be assessed for working day arrives as an "entity" at "create" module and then is transferred to "Read/Write" module that is assign "working day" attribute based on soil model output spreadsheets and then is gone to "Decide" module. If the day is workable, is transferred to "Signal" module and number 1 send to "Hold" module in farm machinery sub-model. Otherwise, that day is considered as non-workable and "Dispose" from model. An auxiliary "Decide" module is considered to specify "finish time" to this sub-model. A simplified sketch of this sub-model is shown in Fig. 2. In Farm machinery operation sub-model, each hectare of field to be ploughed, enters as "Entity" to "Create" module with specific time steps and then is send to "Hold" module for determining working day. When the day is workable, the entity can go to "Process" module for each operation. Each machinery set was considered as "Resource" and each operation was considered as individual "Process" module. Afterwards, entity is transferred to "Hold" module for determining finish operation. If the operation is finished or accomplished to some extent, the entity is transferred to next "Station" by means of "Route" module, in expect of "Sowing Operation". A simplified sketch of this sub-model is shown in Fig. 3. Model was started at first day of autumn 1992 and repeated for 21-years period (1992–2012). The priority of operations was harrowing, leveling and sowing, respectively.

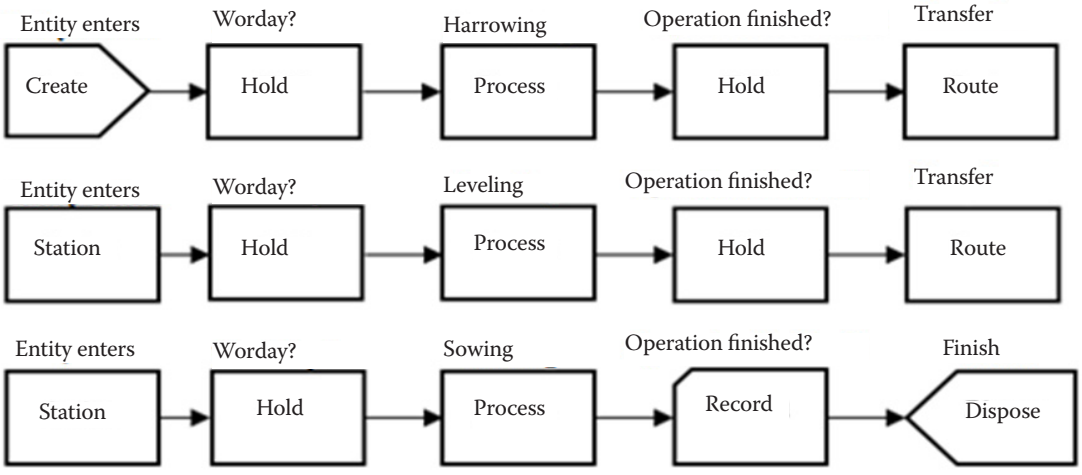

Fig. 3. A simplified sketch of farm machinery operation sub-model

https://doi.org/10.17221/49/2017-RAE

Table 1. Machinery sets characteristics for simulating farm machinery operations

Set	Number of equipment				Number of tractors
	Disk-1	Disk-2	Leveler-1	Planter	
C1	1	–	1	1	1
C2	1	–	1	1	2
C3	1	–	1	1	3
C4	2	–	1	1	3
C5	2	–	2	1	5
C6	–	1	1	1	1
C7	–	1	1	1	2
C8	–	2	1	1	3

Simulation of machinery operations. Common machinery operations were secondary tillage (harrowing and leveling) and sowing for wheat production in autumn. Eight machinery sets (C1-C8) were selected based on availability in this region (Table 1). The differences between these sets were the number and working width of tillage equipment and the number of tractors. All sets used the same planter to remove the effects of working conditions of sowing operation. These operations were simulated for 21-years period (1992–2012) using the simulation model on a 50-hectare "virtual" farm in Mashhad. Field capacity for each machine and working hours were considered 0.67 ha·h^{-1} for harrow-1, leveler and planter and 1.07 ha·h^{-1} for harrow-2 based on Research Station of Ferdowsi University of Mashhad.

Costs estimation. When the finish day for each set was determined according to the output of the simulation model, total cost of each set was calculated using Microsoft Excel 2007 Spreadsheets. This cost includes fixed cost, variable costs and timeliness cost. Fixed costs were depreciation, annual interest rate, taxes, insurance and housing for tractors and equipment but insurance was not considered for equipment. Depreciation costs were calculated based on ASAE Standard ED 230.3 for first year. Purchase prices were given from online farm machinery sales websites and were presented in Table 2. Salvage value (S) and machine life (L) for tractors and equipment were 20% purchase price, 13 and 7 years, respectively based on Ministry of Agriculture statistics (www.amar.org.ir) of 2014. Interest rate (I) was considered 6% and taxes, insurance and housing were assumed 1%, 0.25% and 0.75% of purchase price.

Table 2. Purchase price of tractors and equipment for fixed-costs calculations

Machine	Price (USD)	Width (m)
Tractor	115,600	–
Disk-1	24,000	2.5
Disk-2	52,000	4
Leveler	9,700	3.5
Planter	24,000	4

Variable costs were included fuel, oil and lubrication, repair and maintenance, tire and driver costs for tractors and repair costs for equipment. Fuel cost was calculated according to Eq. (1):

$$F = Hr \times 0.308\ PTO_{\text{maxPTO}} \quad (1)$$

where: Hr – annual working hours for tractor (h); PTO_{maxPTO} – max. power in PTO (kW)

Gasoline cost per liter was 0.07 dollars. In this study, tractors were ITM 399 (Iran Tractor Manufacturing Company, Tabriz-Iran). PTO_{maxPTO} was 70 kW based on product catalogue. Lubrication and maintenance costs were considered about 20–25% fuel cost. Repair and tire costs were assumed 10 and 4% of purchase price and driver wage was 2 dollars per hour (Ministry of Agriculture (Iran) 2014).

The timeliness costs were calculated for sowing operation considering the effect of land preparation operation on sowing start day. So, it was varied based on last day of tillage operation. Moreover, the effect froze/freeze damage was negligible because all sowing periods were selected according to the conditions of this region. These costs were calculated based on two following methods. In average work method, timeliness costs were calculated using the following equation Eq. (2) proposed by ASAE Standards (EP 496.3 FEB2006) for sowing operations in autumn:

$$TC = \frac{K \times A^2 \times Y \times V}{Z \times G \times C_i \times (pwd)} \quad (2)$$

where: TC – timeliness costs (dollars); K – timeliness coefficient; A – area (ha) that was considered 50 hectares in this study; Y – average yield per area for wheat (ton.ha^{-1}); V – value per yield (dollars·.ton^{-1}); Z – four if the operation can be balanced evenly about the optimum time, and should be two if the operation either commences or terminates at the optimum time; C_i – machine capacity (ha·h^{-1}); G – expected time available for field work each day (h); pwd – probability of a working day (decimal)

Timeliness coeficcient K was 0.005, average yield was determined 9.5 t·ha^{-1} and optimum sowing day

https://doi.org/10.17221/49/2017-RAE

was considered October 12th based on the study of Nazeri et al. (2010). Yield value was 0.36 dollars per kilogram (Statistical Center of Iran 2014). Working hours per day was also considered fixed as 7.5 h based upon actual farming practices of the Research Station of Ferdowsi University of Mashhad. This value can be changed based on manager decision. Moreover, *Z* value was 2 for all sets *C*2 and *C*3 and *pwd* was calculated 0.85 for all sets except C1 that was calculated 0.84.

In daily work method, annual yield losses were calculated based on Eq. (3) that was modified form of Eq. (2) (de Toro 2005):

$$Y_i = P_d \times A \times (D_s - D_o) + 0.5 \times P_d \times A \times (D_f - D_s) \quad (3)$$

where: Y_i – annual yield losses for sowing operation (kg); P_d – daily penalty (kg·ha^{-1}·day^{-1}); D_s – the start day for operation (day number); D_o – optimum day for operation (day number); D_f – finish day for operation (day number); A – field area (ha)

If $D_f < D_o$, annual yield losses were equal to zero and if $D_s < D_o$ and $D_f > D_o$, D_s was equal to D_o (de Toro 2005). According to Nazeri et al. (2010), P_d was determined as 48.8 kg. Start day was considered 23th September and timeliness costs were calculated by Eq. (4):

$$TC = Y_i \times V \quad (4)$$

Validation. The output of the simulation model was finish day of each operation and subsequently the length of operation for each machinery set. These results were verified with 10 different farm sizes (between 3–40 ha) during 9 years (2002–2010). Data gathered from farm included field size, machinery set, operational conditions and start and finish days for every operation in each given farm. The simulation model was run under these conditions and the results (the length of each operation) were compared with actual length of that farm operation with *t*-test in SPSS 16 at 5% probability level. Results were shown in Fig. 4. Results obtained from *t*-test showed that there was no significant difference between simulated and actual farms and the correlation coefficient was 0.935.

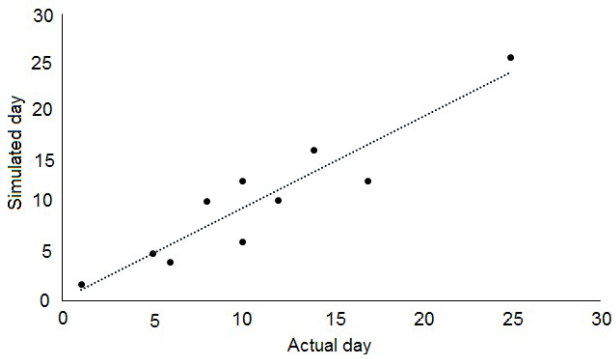

Fig. 4. Comparison of the length of various operations between simulated and actual farms for Research Station of Ferdowsi University of Mashhad during 2002–2010

Sensitivity Analysis. The analysis was performed to measure the sensitivity of selecting the optimum set to changes in field size. For this purpose, field size was changed to 25 and 75-hectare and other parameters were not changed, then simulation model was run, and finish day of each operation was recorded. Finally, the total costs of each set were calculated using spreadsheets and the optimum set was found for every field size.

RESULTS AND DISCUSSION

Cost estimation of machinery sets

Fixed, variable and timeliness costs for both daily and average work methods and also standard deviations for daily work method are shown in Fig. 5. The results showed that total costs were close to each other for C1, C6 and C7 sets. This was due to distribution pattern of costs that the large part of costs was related to timeliness costs in C1 and C6 sets and fixed and variable costs in C7 set. Finally, C1 and C7 sets were selected as optimum sets based on average work method and daily work method, respectively. Based on these results, costs of farm machdepended on distribution of fixed, variable and timeliness costs. So if a small set was selected, fixed and variable costs were low but timeliness cost was high while in a large set, fixed and variable costs were high and timeliness cost was low.

Sensitivity analysis of model

Results of simulation model for 25 and 75-hectare farms were shown in Figs 6 and 7. Timeliness costs due to early crop establishment were not considered in daily work method, and then total costs were larger in C4, C5 and C8 sets for average work method compared to daily work method in the 25-hectare farm. In this farm, the smallest set – C1 – was the optimum set in both methods (Fig. 6). To-

https://doi.org/10.17221/49/2017-RAE

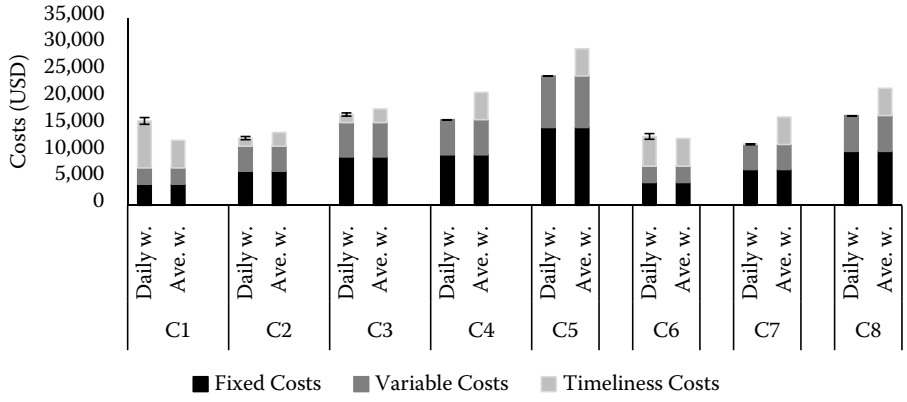

Fig. 5. Total costs of machinery sets calculated by daily and average work methods for secondary tillage and sowing operation based on 21 years simulation

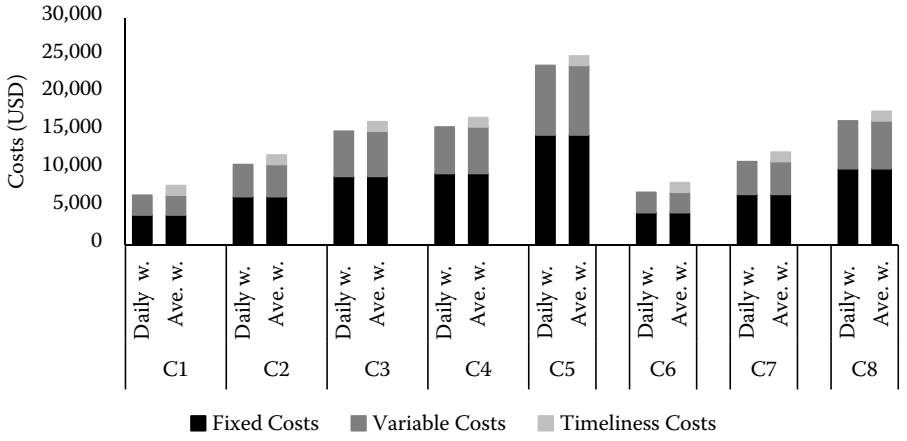

Fig. 6. Total costs for 25-ha farm size calculated by daily and average work methods for secondary tillage and sowing operation based on 21 years simulation

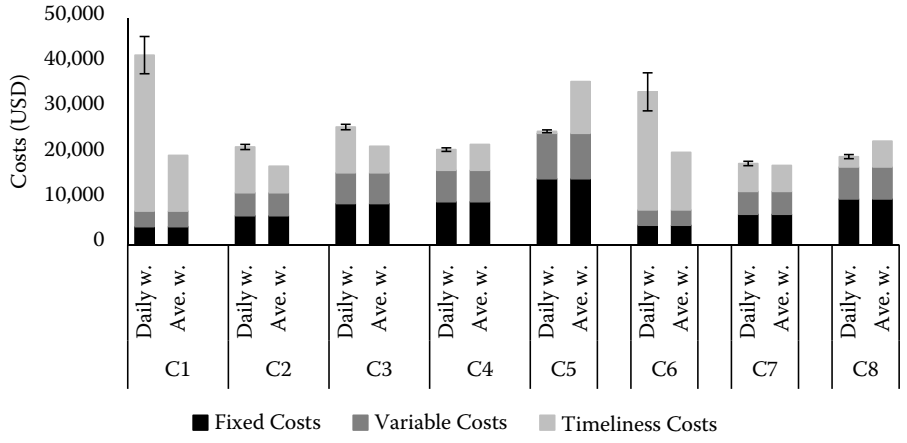

Fig 7. Total costs for 75-hectare farm size calculated by daily and average work methods for secondary tillage and sowing operation based on 21 years simulation

tal costs for C1 and C6 sets were larger in daily work method, because when the number of working days were increased, probability of working days were decreased in the 75-hectare farm. In this farm, the C7 set was the optimum set in both methods (Fig. 7). As the results of model showed, when farm size increased, timeliness costs increased and this was due to confluence to bad weather conditions in late periods so farm machinery size should be increased. Rotz et al. (1983) showed that as the farm size was increased from 200 to 400 ha, sizes of machinery sets were increased by 30% to 40%. Haffar and Khouri (1992) presented that as farm size was increased from 14 to 56 ha, the annual costs increased by 330%. Gunnarsson and Hansson (2004) also illustrated that increasing organic farm size, increased the farm machinery requirement for sowing and harvesting.

Effect of farm size to cost per hectare

For daily work method, the total costs per hectare of C4, C5 and C8 sets decreased due to increasing of farm size (Fig. 8). In C7 and C3 sets, costs per hectare

https://doi.org/10.17221/49/2017-RAE

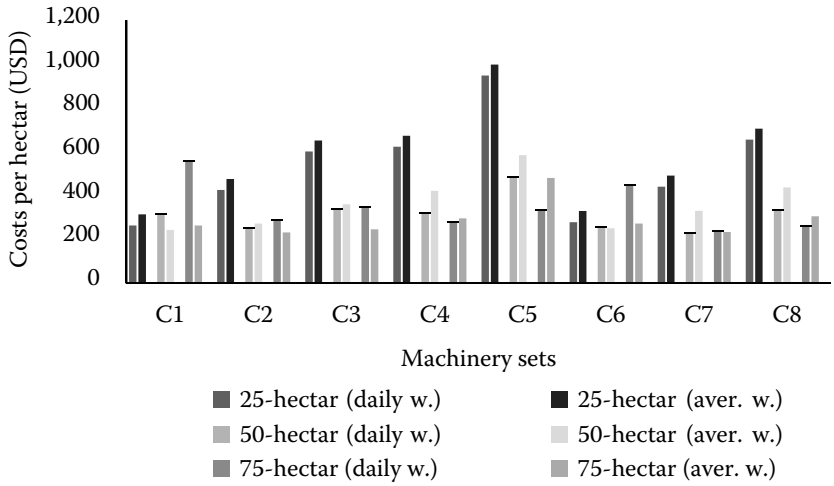

Fig. 8. Costs per hectare for 25, 50 and 75-hectare farm calculated by daily and average work methods for secondary tillage and sowing operation based on 21 years simulation

were relatively equal for 50 and 75-hectare farms and in the other sets this relationship was not confirmed because of excessive timeliness costs for 75-hectare farm. This illustrated that these sets were not suitable for 75-hectare farm due to excessive timeliness costs. In average work method, except of C1 and C6, cost per hectare decreased when farm size increased. In C1 and C6 sets, excessive timeliness costs causing increasing in total costs and then cost per hectare due to not adequate capacity of them. In Rotz et al. (1983) study was shown that costs per hectare will decreased when farm size increased due to higher efficiency of farm machinery in large farms.

Comparison of daily and average work methods

In daily work method, since the output of model should finish every day of each operation and also given the start day, it is possible to determine timeliness costs based on daily basis, whereas in average work method, these costs are calculated for entire period. Moreover, using discrete event simulation needs to have detailed daily weather data, while only probability of working days was needed for average work method. Timeliness costs for early crop establishment was not considered in daily work method however suitable management policies could compensated it.

CONCLUSION

In this study a simulation model for secondary tillage and sowing operations was developed by employing discrete event simulation using Arena language. The outputs of model were completion dates of secondary tillage and sowing operations, so timeliness costs could be determined for a series of years on a daily basis. These findings were compared with results from the Average work method. Generally, the main conclusions are:

There was no significant difference between simulation model output and observed data in farm and present model showed an acceptable performance.

Daily work method requires more data compared with average work method, and its results are more detailed and comprehensive. Moreover, in comparison with daily work method, average work method was not enabled to considered climate uncertainty among studied years. It could be more highlighted in areas with higher annual weather variation. Total costs depend on distribution of fixed, variable and timeliness costs. Thus, smaller machinery sets can have lower fixed and variable and higher timeliness costs.

If detailed historical data are available, the application of simulation techniques for farm machinery management could be used as a suitable tool for determination of total costs (fixed, variable and timeliness costs) and optimization of them.

Acknowledgments

The authors would like to appreciate the Research Station of Ferdowsi University of Mashhad for providing the required data. We also like to thank Professor Alfredo de Toro for his valuable comments that greatly improved this manuscript.

https://doi.org/10.17221/49/2017-RAE

References

Al-Hamed S. A., Al-Janobi A. A. (2001): An object-oriented program to predict tractor and machine system performance. Research Bulletin, King Saud University, 106: 5–24.

ASAE (2006): Agricultural Machinery Management ASAE EP496.3.

Bannayan M., Lakzian A., Gorbanzadeh N., Roshani A. (2011): Variability of growing season indices in northeast of Iran. Theoretical and Applied Climatology, 105: 485–494.

Camarena E.A., Gracia C., Sixto J.M.C. (2004): A mixed integer linear programming machinery selection model for multifarm systems. Biosystems Engineering, 87: 145–154.

Dash R.C., Sirohi N.P.S. (2008): A computer model to select optimum size of farm power and machinery for paddy-wheat crop rotation in Northern India. Agricultural Engineering International: the CIGR Ejournal: 12.

Gunnarsson C., Hansson P.-A. (2004): Optimisation of field machinery for an arable farm converting to organic farming. Agricultural Systems, 80: 85–103.

Haffar I., Khoury R. (1992): A computer model for field machinery selection under multiple cropping. Computers and Electronics in Agriculture, 7: 219–229.

Koocheki A., Shabahng J., Khorramdel S., Azimi R., Aghel H. (2011): Documentation of farming management with GIS and ArcView: A case study for agricultural Research Station of Faculty of Agriculture, Ferdowsi University of Mashhad, Iran. Journal of Iranian Field Crop Research, 6: 909–919. (in Farsi).

Kosari Moghaddam A. (2014): Optimization of tillage machinery selection in grain farms using discrete event simulation.[Master's Thesis.] Ferdowsi University of Mashhad (Iran) (in Farsi). Abstract available on http://thesis.um.ac.ir/moreinfo-56053-pg-1.html

Ministry of Agriculture (Iran) (2014): Agricultural Jihad Machinery Development Center. Estimation of Tariff of Mechanization Services in Iran.

Nazeri M.A., Abadi A. Z.F., Koohestani B., Mirak T.N. (2010): Investigation on the response of different wheat types in suitable and delayed sowing day in Mashhad climatic conditions. 11th Iranian Crop Science congress. Environmental Sciences Research Institute, Shahid Beheshti University, Tehran. (in Farsi).

Ogunlowo A.S. (1997): Machinery selection based on gross-margin costing analysis: a case Study of Abeokuta local government aeras in Nigeria. West Indian Journal of Engineering: 40–48.

Rotz C.A., Harrigan T.M. (2005): Predicting suitable days for field machinery operations in a whole farm simulation. Applied Engineering in Agriculture, 21: 10.

Rotz C.A., Muthar H.A., Black J.R. (1983): A multiple crop machinery selection algorithm. Transaction of ASAE: 1644–1649.

Sahu R.K., Raheman H. (2008): A decision support system on matching and field performance prediction of tractor-implement system. Computers and Electronics in Agriculture, 60: 76–86.

Søgaard H.T., Sørensen C.G. (2004): A model for optimal selection of machinery sizes within the farm machinery system. Biosystems Engineering, 89: 13–28.

Statistical Center of Iran. (2014): Agricultural services costs and products prices. Available at http://www.amar.org.ir/Portals/0/Files/reports/1393/g_ghmvhkhk_93.pdf (in Farsi).

de Toro A. (2005): Influences on timeliness costs and their variability on arable farms. Biosystems Engineering, 92: 1–13.

de Toro A., Hansson P.-A. (2004): Analysis of field machinery performance based on daily soil workability state using discrete event simulation or on average workday probability. Agricultural Systems, 24: 109–129.

Received for publication April 28, 2017
Accepted after corrections January 29, 2017