CentralPro – An Excel Growth Simulator for Mixed-Species Hardwood Forests in Indiana (Beta Version)

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July, 2020

Introduction

This is a program developed to work with Microsoft Excel ® for simulating the growth and management of mixed-species hardwood forests located in Indiana, USA. The underlying growth model supporting this Excel program is described in Ma et al. (2016) and Wang et al. (2020).

A forest stand is represented by the number of trees per hectare in each of 17 size classes in seven species groups. The seven species groups are: White oak (WO), Red oak (RO), Black walnut (BW), Black cherry (BC), Maple (MP), Soft wood (SW), Other Angiosperms (OA). The seventeen diameter classes are of 5-cm increments, except for the first class (2.54–7 cm) and the last (82 cm and above) class.

This program allows users to predict stand development from a specific initial state for a given period. Both deterministic and stochastic simulations can be performed. The latter are based on forest fire impacts as described in Ma et al. (2016). Users can choose whether or not to include forest fire to generate simulations. Users can also specify various management regimes such as the cutting cycle (the interval between harvests) and cutting intensity (the percentage of growing stock to remove). The tabulated results show the volume of harvest, residual basal area, and the net present value (NPV).

This manual documents the instructions on how to use the program to generate simulation results. It also illustrates how to read the results by providing two practical examples. This will also help the user learn how to enter the input data, choose the options, start the program, execute a simulation, and understand the output tables.

Requirements

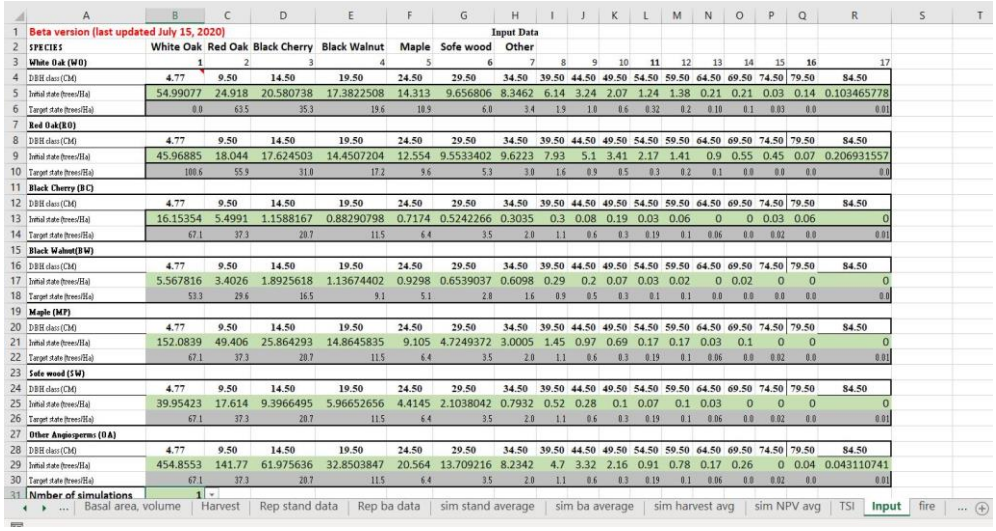
You need the following hardware and software to operate the simulator:

- A personal computer
- Microsoft Excel ® 2007 or above
- A free copy of the simulator program downloadable from

  https://ag.purdue.edu/facai/data/

Initializing the Simulator

After downloading the program onto your computer, you can open the program directly by clicking on the downloaded Excel file. Navigate to the "**Input"** Worksheet (Fig.1). This worksheet contains all the input cells, where you can enter the required stand information and choose the various input options provided in different sections of the worksheet



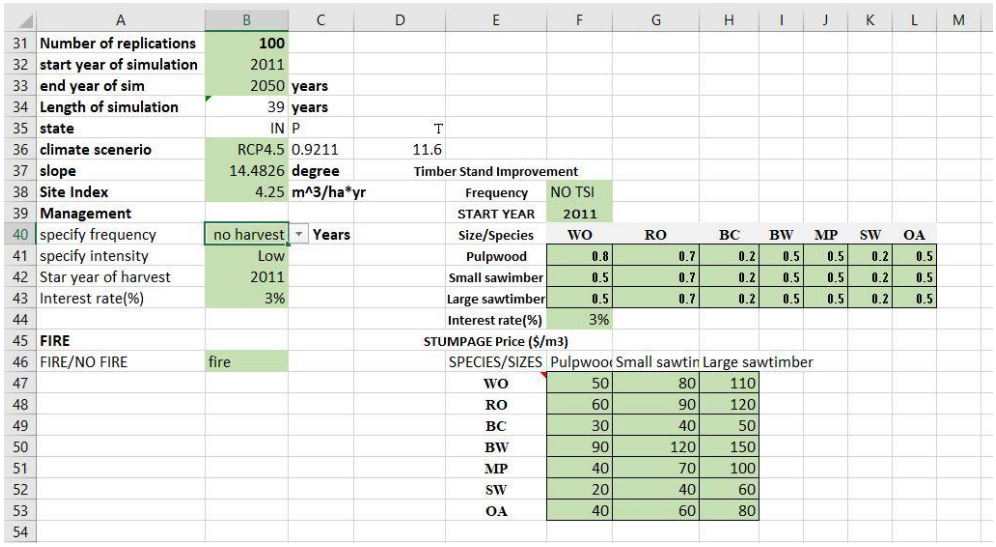
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Beta version (last updated July 15, 2020)							Input Data												
2	SPECIES	White Oak	Red Oak	Black Cherry	Black Walnut	Maple	Sofe wood	Other												
3	White Oak (WO)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
4	DBH class (CM)	4.77	9.50	14.50	19.50	24.50	29.50	34.50	39.50	44.50	49.50	54.50	59.50	64.50	69.50	74.50	79.50	84.50		
5	Initial state (trees/HA)	54.99077	24.918	20.580738	17.3822508	14.313	9.656806	8.3462	6.14	3.24	2.07	1.24	1.38	0.21	0.21	0.03	0.14	0.103465778		
6	Target state (trees/HA)	0.0	63.5	35.3	19.6	10.9	6.0	3.4	1.9	1.0	0.6	0.32	0.2	0.10	0.1	0.03	0.0	0.01		
7	Red Oak(RO)																			
8	DBH class (CM)	4.77	9.50	14.50	19.50	24.50	29.50	34.50	39.50	44.50	49.50	54.50	59.50	64.50	69.50	74.50	79.50	84.50		
9	Initial state (trees/HA)	45.96885	18.044	17.624503	14.4507204	12.554	9.5533402	9.6223	7.93	5.1	3.41	2.17	1.41	0.9	0.55	0.45	0.07	0.206931557		
10	Target state (trees/HA)	100.6	55.9	31.0	17.2	9.6	5.3	3.0	1.6	0.9	0.5	0.3	0.2	0.1	0.0	0.0	0.0	0.0		
11	Black Cherry (BC)																			
12	DBH class (CM)	4.77	9.50	14.50	19.50	24.50	29.50	34.50	39.50	44.50	49.50	54.50	59.50	64.50	69.50	74.50	79.50	84.50		
13	Initial state (trees/HA)	16.15354	5.4991	1.1588167	0.88290798	0.7174	0.5242266	0.3035	0.3	0.08	0.19	0.03	0.06	0	0	0.03	0.06	0		
14	Target state (trees/HA)	67.1	37.3	20.7	11.5	6.4	3.5	2.0	1.1	0.6	0.3	0.19	0.1	0.06	0.0	0.02	0.0	0.01		
15	Black Walnut(BW)																			
16	DBH class (CM)	4.77	9.50	14.50	19.50	24.50	29.50	34.50	39.50	44.50	49.50	54.50	59.50	64.50	69.50	74.50	79.50	84.50		
17	Initial state (trees/HA)	5.567816	3.4026	1.8925618	1.13674402	0.9298	0.6539037	0.6098	0.29	0.2	0.07	0.03	0.02	0	0.02	0	0	0		
18	Target state (trees/HA)	53.3	29.6	16.5	9.1	5.1	2.8	1.6	0.9	0.5	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0		
19	Maple (MP)																			
20	DBH class (CM)	4.77	9.50	14.50	19.50	24.50	29.50	34.50	39.50	44.50	49.50	54.50	59.50	64.50	69.50	74.50	79.50	84.50		
21	Initial state (trees/HA)	152.0839	49.406	25.864293	14.8645835	9.105	4.7249372	3.0005	1.45	0.97	0.69	0.17	0.17	0.03	0.1	0	0	0		
22	Target state (trees/HA)	67.1	37.3	20.7	11.5	6.4	3.5	2.0	1.1	0.6	0.3	0.19	0.1	0.06	0.0	0.02	0.0	0.01		
23	Sofe wood (SW)																			
24	DBH class (CM)	4.77	9.50	14.50	19.50	24.50	29.50	34.50	39.50	44.50	49.50	54.50	59.50	64.50	69.50	74.50	79.50	84.50		
25	Initial state (trees/HA)	39.95423	17.614	9.3966495	5.96652656	4.4145	2.1038042	0.7932	0.52	0.28	0.1	0.07	0.1	0.03	0	0	0	0		
26	Target state (trees/HA)	67.1	37.3	20.7	11.5	6.4	3.5	2.0	1.1	0.6	0.3	0.19	0.1	0.06	0.0	0.02	0.0	0.01		
27	Other Angiosperms (OA)																			
28	DBH class (CM)	4.77	9.50	14.50	19.50	24.50	29.50	34.50	39.50	44.50	49.50	54.50	59.50	64.50	69.50	74.50	79.50	84.50		
29	Initial state (trees/HA)	454.8553	141.77	61.975636	32.8503847	20.564	13.709216	8.2342	4.7	3.32	2.16	0.91	0.78	0.17	0.26	0	0.04	0.043110741		
30	Target state (trees/HA)	67.1	37.3	20.7	11.5	6.4	3.5	2.0	1.1	0.6	0.3	0.19	0.1	0.06	0.0	0.02	0.0	0.01		
31	Nmber of simulations	1																		

Basal area, volume | Harvest | Rep stand data | Rep ba data | sim stand average | sim ba average | sim harvest avg | sim NPV avg | TSI | Input | fire

Figure 1. Display of input worksheet showing initial stand input cells

. In Figure 1, all the rows colored in light green which are labeled "**Initial state**" require information of the initial number of trees per hectare in the stand at the beginning of the simulation, by seven species groups and 17 diameter classes as defined in Ma et al. (2016). The rows labeled "**Target state**" are for future extension of the program thus not requiring any inputs at this moment.

After entering the initial stand condition, there are other cells requiring inputs within the same "**Input"** worksheet by the user, shown in Figure 2. The explanation of each input variable is as follow:



	A	B	C	D	E	F	G	H	I	J	K	L	M
31	**Number of replications**	**100**											
32	**start year of simulation**	2011											
33	**end year of sim**	2050	**years**										
34	**Length of simulation**	39	**years**										
35	**state**	IN	P	T									
36	**climate scenerio**	RCP4.5	0.9211	11.6									
37	**slope**	14.4826	**degree**		**Timber Stand Improvement**								
38	**Site Index**	4.25	**m^3/ha*yr**		**Frequency**	NO TSI							
39	**Management**				**START YEAR**	**2011**							
40	specify frequency	no harvest	**Years**		**Size/Species**	**WO**	**RO**	**BC**	**BW**	**MP**	**SW**	**OA**	
41	specify intensity	Low			**Pulpwood**	**0.8**	**0.7**	**0.2**	**0.5**	**0.5**	**0.2**	**0.5**	
42	Star year of harvest	2011			**Small sawimber**	**0.5**	**0.7**	**0.2**	**0.5**	**0.5**	**0.2**	**0.5**	
43	Interest rate(%)	3%			**Large sawtimber**	**0.5**	**0.7**	**0.2**	**0.5**	**0.5**	**0.2**	**0.5**	
44					**Interest rate(%)**	3%							
45	**FIRE**				**STUMPAGE Price ($/m3)**								
46	FIRE/NO FIRE	fire			SPECIES/SIZES	Pulpwoo	Small sawtin	Large sawtimber					
47					**WO**	50	80	110					
48					**RO**	60	90	120					
49					**BC**	30	40	50					
50					**BW**	90	120	150					
51					**MP**	40	70	100					
52					**SW**	20	40	60					
53					**OA**	40	60	80					
54													

Figure 2. Display of input variables within input worksheet

(1) **Number of repetitions**: The program is capable of performing multiple repetitions of a simulation. The purpose of the repetitions is to capture variations due to random elements in the stochastic simulation. If only simulating the deterministic result, this number needs to be left at its default value, "1" ,as all the repetitions yield the same result. When the option of "**Forest fire**" is chosen, the user needs to determine the number of simulations to generate. The results of all simulations can be found in the worksheet named "**Rep**", to be explained later in this document. It is important to note that

stochastic simulations only predict forest growth without management; management options are not allowed in this case.

(2) **Start year of simulation**, **End year of simulation**, **Length of simulation**: All simulations start from " **Start year of simulation**" and end in the "**End year of simulation"**, as specified by the user. The "**Length of simulation**" will then be automatically calculated**.** The end year should be greater than the start year to avoid errors.

(3) **Climate scenario:** This program accommodates four time-dependent Representative Concentration Pathway (RCP) scenarios: RCP2.6, RCP4.5, RCP6.0 and RCP8.5. There is also an option to choose a constant climate represented by the average growing-season temperature (T) and precipitation (P), located to the right of the climate scenario option. The user thus can generate results specific to one of the five climate scenarios.

(4) **Slope** and **Site index:** These values can also be specified by the user. The default values are the mean values of the sample plots in Indiana.

(5) **Management:** This section has three input options.

   a. Specify frequency: The user specifies a thinning frequency from the drop-down list: (1) no-harvest, (2) 10 years, and (3) 20 years.

   b. Specify intensity: The user chooses a harvesting intensity, i.e., the proportion of trees in a stand that needs to be removed. The list of options contains low, medium and high. Low corresponds to removing only 20% of trees across all species and sizes, medium to 50%, and high to 80%.

   c. Specify start year of harvest: This option lets the user choose a year from when they want to implement harvesting regime. It can be any year between the starting and ending years of the simulation.

d. **Interest rate:** The interest rate is assumed constant over time, with a default value of 3% per year. The user can specify a different rate when calculating the NPV.

(6) **TSI:** This section allows the user to implement timber stand improvement (TSI) practices. The three input cells, **Frequency** and **Start year, Interest rate** are similar to that in the **Management** section, except that here there is one extra option of five-year cycle to give a more frequent thinning option. The key difference is in the following three rows of inputs, specifying intensity by species groups and commercial sizes. Note that three commercial sizes are defined as: pulpwood (25cm to 33cm), small-sawtimber (33 to 40), and large-sawtimber (40cm and above). The user can specify an intensity of thinning for each of the 21 combinations, by entering a number between 0 and 1, 0 being not removing anything and 1 being harvest all.

(7) **FIRE:** This is the option to decide whether to include forest fire as a random event in the simulation. If the user chooses "yes", then the growth model becomes stochastic and if "no" is chosen, it remains as a deterministic model. For the definition of fire impacts, please refer to Ma et al. (2016).

(8) **Stumpage prices:** This section has the same seven species groups and three commercial size classes as in the **TSI** section. The user can enter values to reflect the stumpage price for each specific category.

How to Run the Simulator?

Once all the required fields are entered correctly, the user can run the simulator by taking one of the approaches as described below.

(1) **Go to** Developers tab **>** Macros > **Run** (Fig.3)

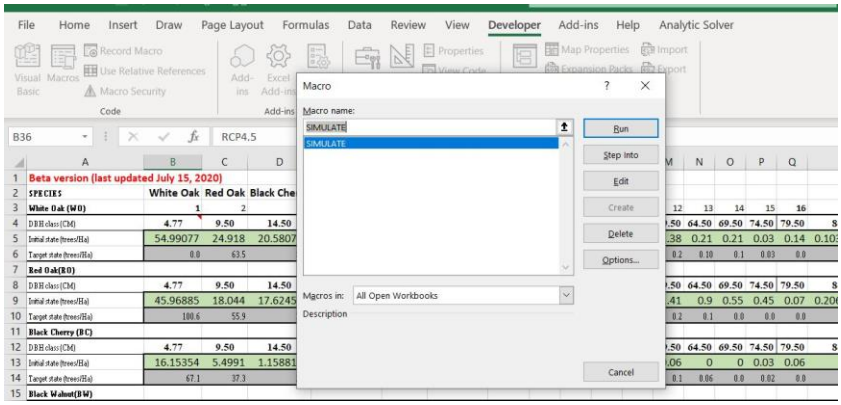


Figure 3. Location of "run" in excel

If the user doesn't have a developers tab present, they can customize their ribbon to add developer's tab by following this step-

a. Go to file > Options > customize ribbon > on main tabs check **Developer**

(2) Alternate method to run macro without developer,

- Go to View tab > Macros(at the right end of the list) > view macros > **Run**

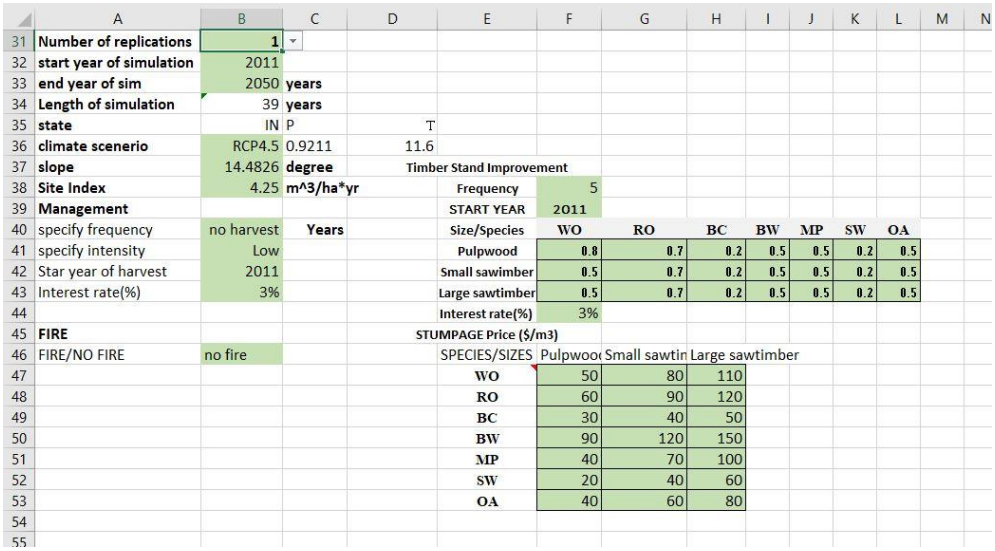
After starting the macro, it will take Excel some time to run the program and generate simulations. The running time depends on the **length of simulation**, and the **number of repetitions.** Generally it should take somewhere from less than one minute to several minutes. The user can find the summarized results in the "**Input**" worksheet and the other simulation results in the other sheets within the Excel file. Two examples are provided below to illustrate how to read the results. Once a new simulation has started, the simulator will replace all old tables and charts with the new ones. For this reason, you should save the workbook as a different file after each simulation.

EXAMPLE-1: Deterministic Simulation with TSI

Here we perform simulations based on the deterministic part of the model, i.e., we choose, **Fire =** "NO" in the input section. For a given initial condition of a stand, we obtain the results of the volume of harvests, NPV of harvests, and residual basal area.

Setting Simulation Parameters:

The number of repetitions is selected to be "1", as it is a deterministic simulation. Next, the start year and end year of simulations are set as 2011 and 2050, respectively. We then choose **Climate scenario-RCP4.5.** Both the slope and site index are left at their default values: **14.5** degrees and **4.3** m^3 $ha^{-1}yr^{-1}$ respectively. We will select "no management" as TSI will be implemented. We set the frequency and intensity along with the first year of TSI in the **TSI** section. All these inputs can be seen in Figure 4.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
31	**Number of replications**	**1**												
32	**start year of simulation**	2011												
33	**end year of sim**	2050	**years**											
34	**Length of simulation**	39	**years**											
35	**state**	IN	P	T										
36	**climate scenerio**	RCP4.5	0.9211	11.6										
37	**slope**	14.4826	**degree**		**Timber Stand Improvement**									
38	**Site Index**	4.25	**m^3/ha*yr**		**Frequency**	5								
39	**Management**				**START YEAR**	**2011**								
40	specify frequency	no harvest	**Years**		**Size/Species**	**WO**	**RO**	**BC**	**BW**	**MP**	**SW**	**OA**		
41	specify intensity	Low			**Pulpwood**	**0.8**	**0.7**	**0.2**	**0.5**	**0.5**	**0.2**	**0.5**		
42	Star year of harvest	2011			**Small sawimber**	**0.5**	**0.7**	**0.2**	**0.5**	**0.5**	**0.2**	**0.5**		
43	Interest rate(%)	3%			**Large sawtimber**	**0.5**	**0.7**	**0.2**	**0.5**	**0.5**	**0.2**	**0.5**		
44					**Interest rate(%)**	3%								
45	**FIRE**				**STUMPAGE Price ($/m3)**									
46	FIRE/NO FIRE	no fire			SPECIES/SIZES	Pulpwoo	Small sawtin	Large sawtimber						
47					**WO**	50	80	110						
48					**RO**	60	90	120						
49					**BC**	30	40	50						
50					**BW**	90	120	150						
51					**MP**	40	70	100						
52					**SW**	20	40	60						
53					**OA**	40	60	80						
54														
55														

Figure 4. Display of all the input parameter for example-1

Simulation Output

The NPV and harvested volume (Fig.5) are summarized in the **Input Data** worksheet, while the other worksheets contain much detailed data of the simulation.

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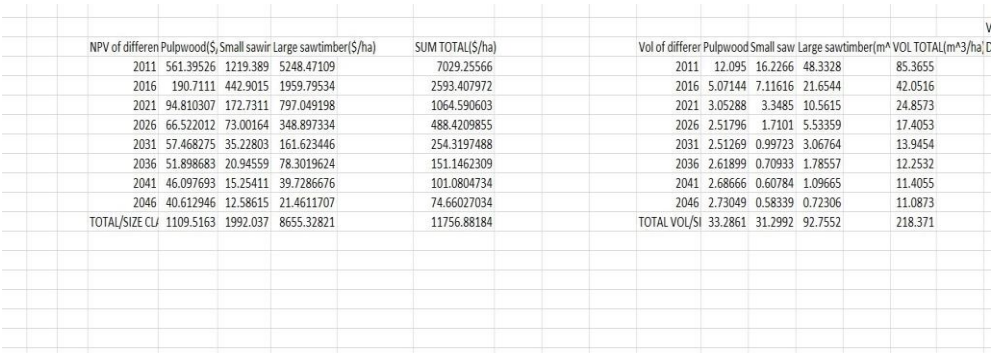


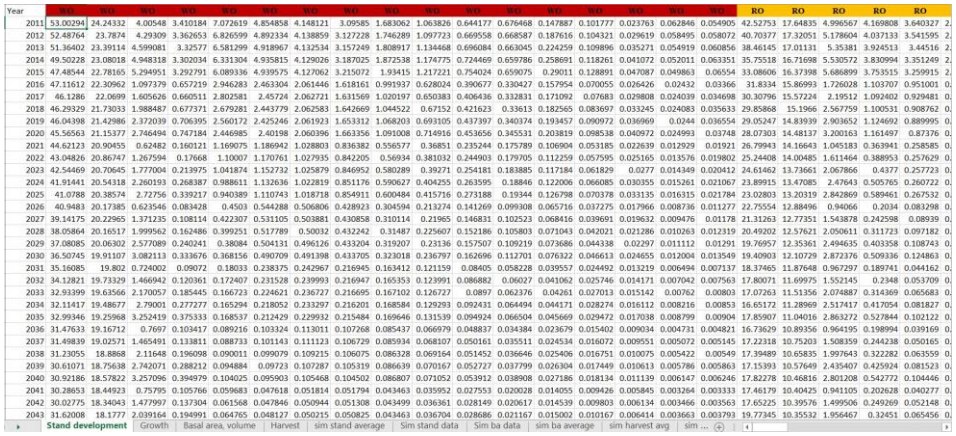
NPV of differen	Pulpwood($,	Small sawir	Large sawtimber($/ha)	SUM TOTAL($/ha)
2011	561.39526	1219.389	5248.47109	7029.25566
2016	190.7111	442.9015	1959.79534	2593.407972
2021	94.810307	172.7311	797.049198	1064.590603
2026	66.522012	73.00164	348.897334	488.4209855
2031	57.468275	35.22803	161.623446	254.3197488
2036	51.898683	20.94559	78.3019624	151.1462309
2041	46.097693	15.25411	39.7286676	101.0804734
2046	40.612946	12.58615	21.4611707	74.66027034
TOTAL/SIZE CL/	1109.5163	1992.037	8655.32821	11756.88184

Vol of differer	Pulpwood	Small saw	Large sawtimber(m^	VOL TOTAL(m^3/ha/
2011	12.095	16.2266	48.3328	85.3655
2016	5.07144	7.11616	21.6544	42.0516
2021	3.05288	3.3485	10.5615	24.8573
2026	2.51796	1.7101	5.53359	17.4053
2031	2.51269	0.99723	3.06764	13.9454
2036	2.61899	0.70933	1.78557	12.2532
2041	2.68666	0.60784	1.09665	11.4055
2046	2.73049	0.58339	0.72306	11.0873
TOTAL VOL/SI	33.2861	31.2992	92.7552	218.371

Figure 5.Display of NPV result generated through simulation

Stand development worksheet- This worksheet (Fig. 6) shows the number of trees per hectare on the stand after harvests by species and diameter class, for each year of the simulation. Scrolling to the right reveals the tree distribution for other species and sizes. Scrolling down reveals the result for more years.

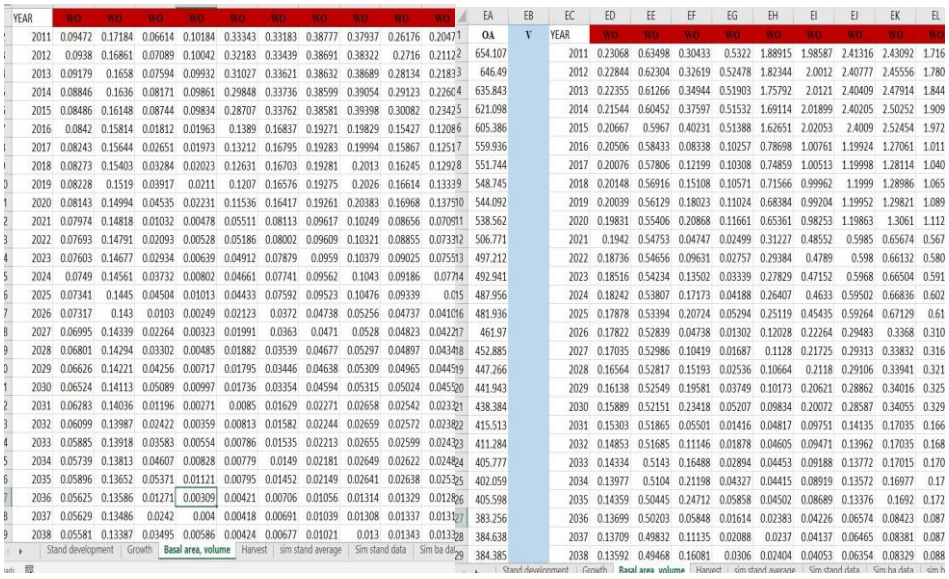
Basal area, volume worksheet- This worksheet (Fig. 7) shows, for each year, the basal area and volume of each species and size corresponding to the number of trees in the ***stand development*** worksheet.



Year	WO	WO	WO	WO	WO	WO	WO	WO	WO	WO	WO	WO	WO	WO	WO	WO	RO	RO	RO	RO	RO
2011	53.00294	24.24332	4.00548	3.410184	7.072619	4.854858	4.148121	3.09585	1.683062	1.063826	0.644177	0.676468	0.147887	0.101777	0.023763	0.062846	0.054905	42.52753	17.64835	4.996567	4.169808	3.640327	2.
2012	52.48764	23.7874	4.29309	3.362653	6.826599	4.892334	4.138859	3.127228	1.746289	1.097723	0.669558	0.668587	0.187616	0.104321	0.029619	0.058495	0.058072	40.70377	17.32051	5.178604	4.037133	3.541595	2.
2013	51.36402	23.39114	4.599081	3.32577	6.581299	4.918967	4.132534	3.157249	1.808917	1.134468	0.696084	0.663045	0.224259	0.109896	0.035271	0.054919	0.060856	38.46145	17.01131	5.35381	3.924513	3.44516	2.
2014	49.50228	23.08018	4.948318	3.302034	6.331304	4.935815	4.129026	3.187025	1.872538	1.174775	0.724469	0.659786	0.258691	0.118261	0.041072	0.052011	0.063351	35.75518	16.71698	5.530572	3.830994	3.351249	2.
2015	47.48544	22.78165	5.294951	3.292791	6.089336	4.939575	4.127062	3.215072	1.93415	1.217221	0.754024	0.659075	0.29011	0.128891	0.047087	0.049863	0.06554	33.08606	16.37398	5.686899	3.753515	3.259915	2.
2016	47.11612	22.30962	1.097379	0.657219	2.946283	2.463304	2.061446	1.618161	0.991937	0.628024	0.390677	0.330427	0.157954	0.070055	0.026426	0.02432	0.03366	31.8334	15.86993	1.726028	1.103707	0.951001	0.
2017	46.1286	22.0699	1.605626	0.660511	2.802581	2.45724	2.062721	1.631569	1.020197	0.650383	0.406436	0.332831	0.171092	0.07683	0.029808	0.024039	0.034698	30.30796	15.57224	2.19512	1.092402	0.929481	0.
2018	46.29329	21.73033	1.988487	0.677371	2.679281	2.443779	2.062583	1.642669	1.044522	0.67152	0.421623	0.33613	0.182565	0.083697	0.033245	0.024083	0.035633	29.85868	15.1966	2.567759	1.100531	0.908762	0.
2019	46.04398	21.42986	2.372039	0.706395	2.560172	2.425246	2.061923	1.653312	1.068203	0.693105	0.437397	0.340374	0.193457	0.090972	0.036969	0.0244	0.036554	29.05247	14.83939	2.903652	1.124692	0.889995	0.
2020	45.56563	21.15377	2.746494	0.747184	2.446985	2.40198	2.060396	1.663356	1.091008	0.714916	0.453656	0.345531	0.203819	0.098538	0.040972	0.024993	0.03748	28.07303	14.48137	3.200163	1.161497	0.87376	0.
2021	44.62123	20.90455	0.62482	0.160121	1.169075	1.186942	1.028803	0.836382	0.556577	0.36851	0.235244	0.175789	0.106904	0.053185	0.022639	0.012929	0.01921	26.79943	14.16643	1.045183	0.363941	0.258585	0.
2022	43.04826	20.86747	1.267594	0.17668	1.10007	1.170761	1.027935	0.842205	0.56934	0.381032	0.244903	0.179705	0.112259	0.057595	0.025165	0.013576	0.019802	25.24408	14.00485	1.611464	0.388953	0.257629	0.
2023	42.54469	20.70645	1.777004	0.213975	1.041874	1.152732	1.025879	0.846952	0.580289	0.39271	0.254181	0.183885	0.117184	0.061829	0.0277	0.014349	0.020412	24.61462	13.73661	2.067866	0.4377	0.257723	0.
2024	41.91441	20.54318	2.260193	0.268387	0.988611	1.132636	1.022819	0.851176	0.590627	0.404255	0.263595	0.18846	0.122006	0.066085	0.030355	0.015261	0.021067	23.89915	13.47085	2.47643	0.505765	0.260722	0.
2025	41.0788	20.38574	2.72756	0.339217	0.940389	1.110743	1.018718	0.854911	0.600484	0.415716	0.273188	0.19344	0.126798	0.070378	0.033135	0.016315	0.021784	23.02803	13.20319	2.842869	0.589461	0.267532	0.
2026	40.9483	20.17385	0.623546	0.083428	0.4503	0.544288	0.506806	0.428923	0.304594	0.213274	0.141269	0.099308	0.065716	0.037275	0.017966	0.008736	0.011277	22.75554	12.88496	0.94066	0.2034	0.083298	0.
2027	39.14175	20.22965	1.371235	0.108114	0.422307	0.531105	0.503881	0.430858	0.310114	0.21965	0.146831	0.102523	0.068416	0.039691	0.019632	0.009476	0.01178	21.31263	12.77351	1.543878	0.242598	0.08939	0.
2028	38.05864	20.16517	1.999562	0.162486	0.399251	0.517789	0.50032	0.432242	0.31487	0.225607	0.152186	0.105803	0.071043	0.042021	0.021286	0.010263	0.012319	20.49202	12.57621	2.050611	0.311723	0.097182	0.
2029	37.08085	20.06302	2.577089	0.240241	0.38084	0.504131	0.496126	0.433204	0.319207	0.23136	0.157507	0.109219	0.073686	0.044338	0.02297	0.011112	0.01291	19.76957	12.35361	2.494635	0.403358	0.108743	0.
2030	36.50745	19.91107	3.082113	0.333676	0.368156	0.490709	0.491398	0.433705	0.323018	0.236797	0.162696	0.112701	0.076322	0.046613	0.024655	0.012004	0.013549	19.40903	12.10729	2.872376	0.509336	0.124863	0.
2031	35.16085	19.802	0.724002	0.09072	0.18033	0.238375	0.242967	0.216945	0.163412	0.121159	0.08405	0.058228	0.039557	0.024492	0.013219	0.006494	0.007137	18.37465	11.87648	0.967297	0.189741	0.044162	0.
2032	34.12821	19.73329	1.466942	0.120361	0.172407	0.231528	0.239993	0.216947	0.165353	0.123991	0.086882	0.06027	0.041062	0.025746	0.014171	0.007042	0.007563	17.80071	11.69975	1.552145	0.2348	0.053709	0.
2033	32.93399	19.63566	2.170057	0.185445	0.166723	0.224621	0.236727	0.216695	0.167102	0.126727	0.0897	0.062376	0.04261	0.027013	0.015142	0.00762	0.00803	17.07263	11.51356	2.074887	0.314369	0.065683	0.
2034	32.11417	19.48677	2.79001	0.277277	0.165294	0.218052	0.233297	0.216201	0.168584	0.129293	0.092431	0.064494	0.044171	0.028274	0.016112	0.008216	0.00853	16.65172	11.28969	2.517417	0.417054	0.081827	0.
2035	32.99346	19.25968	3.252419	0.375333	0.168537	0.212429	0.229932	0.215484	0.169646	0.131539	0.094924	0.066504	0.045669	0.029472	0.017038	0.008799	0.00904	17.85907	11.04016	2.863272	0.527844	0.102122	0.
2036	31.47633	19.16712	0.7697	0.103417	0.089216	0.103324	0.113011	0.107268	0.085437	0.066979	0.048837	0.034384	0.023679	0.015402	0.009034	0.004731	0.004821	16.73629	10.89356	0.964195	0.198994	0.039169	0.
2037	31.49839	19.02571	1.465491	0.133811	0.088733	0.101143	0.111123	0.106729	0.085934	0.068107	0.050161	0.035511	0.024534	0.016072	0.009551	0.005072	0.005145	17.22318	10.75203	1.508359	0.244238	0.050165	0.
2038	31.23055	18.8868	2.11648	0.196098	0.090011	0.099079	0.109215	0.106075	0.086328	0.069164	0.051452	0.036646	0.025406	0.016751	0.010075	0.005422	0.00549	17.39489	10.65835	1.997643	0.322282	0.063559	0.
2039	30.61071	18.75638	2.742071	0.288212	0.094884	0.09723	0.107287	0.105319	0.086639	0.070167	0.052727	0.037799	0.026304	0.017449	0.010613	0.005786	0.005863	17.15393	10.57649	2.435407	0.425924	0.081523	0.
2040	30.92186	18.57822	3.257096	0.394979	0.104025	0.095903	0.105468	0.104502	0.086807	0.071052	0.053912	0.038908	0.027186	0.018134	0.011139	0.006147	0.006246	17.82278	10.46816	2.801208	0.542772	0.104446	0.
2041	30.28653	18.44923	0.75795	0.105766	0.059683	0.047618	0.051814	0.051794	0.043463	0.035952	0.027553	0.020028	0.014055	0.009426	0.005845	0.003264	0.003333	17.46179	10.40425	0.941105	0.202628	0.040277	0.
2042	30.02775	18.34043	1.477997	0.137304	0.061568	0.047846	0.050944	0.051308	0.043499	0.036361	0.028149	0.020617	0.014539	0.009803	0.006134	0.003466	0.003563	17.65225	10.39576	1.499506	0.249269	0.052148	0.
2043	31.62008	18.1777	2.039164	0.194991	0.064765	0.048127	0.050215	0.050825	0.043463	0.036704	0.028686	0.021167	0.015002	0.010167	0.006414	0.003663	0.003793	19.77345	10.35532	1.956467	0.32451	0.065456	0.

Stand development | Growth | Basal area, volume | Harvest | sim stand average | Sim stand data | Sim ba data | sim ba average | sim harvest avg | sim ...

Figure 6. Display of the Stand development worksheet



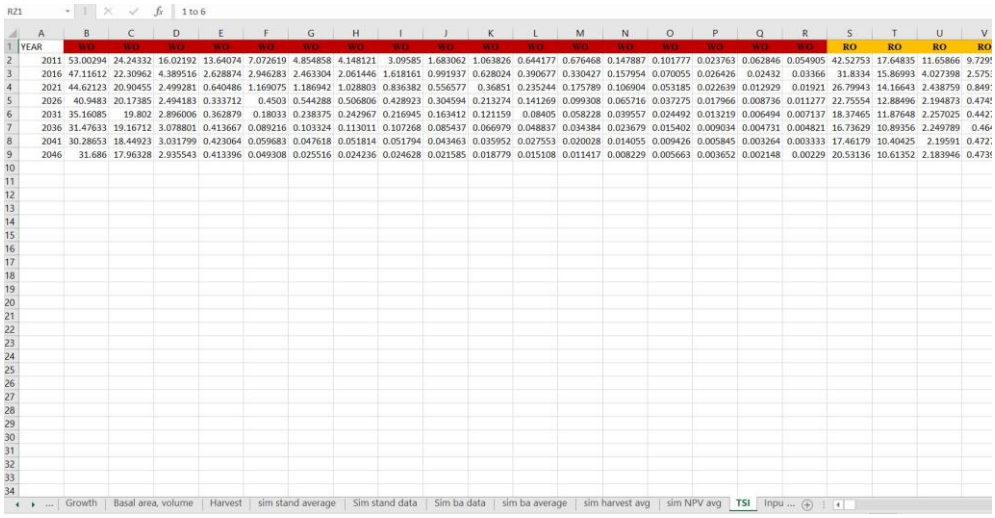
YEAR	WO	WO	WO	WO	WO	WO	WO	WO	WO	WO
2011	0.09472	0.17184	0.06614	0.10184	0.33343	0.33183	0.38777	0.37937	0.26176	0.20471
2012	0.0938	0.16861	0.07089	0.10042	0.32183	0.33439	0.38691	0.38322	0.2716	0.21122
2013	0.09179	0.1658	0.07594	0.09932	0.31027	0.33621	0.38632	0.38689	0.28134	0.21833
2014	0.08846	0.1636	0.08171	0.09861	0.29848	0.33736	0.38599	0.39054	0.29123	0.22604
2015	0.08486	0.16148	0.08744	0.09834	0.28707	0.33762	0.38581	0.39398	0.30082	0.23425
2016	0.0842	0.15814	0.01812	0.01963	0.1389	0.16837	0.19271	0.19829	0.15427	0.12086
2017	0.08243	0.15644	0.02651	0.01973	0.13212	0.16795	0.19283	0.19994	0.15867	0.12517
2018	0.08273	0.15403	0.03284	0.02023	0.12631	0.16703	0.19281	0.2013	0.16245	0.12928
2019	0.08228	0.1519	0.03917	0.0211	0.1207	0.16576	0.19275	0.2026	0.16614	0.13339
2020	0.08143	0.14994	0.04535	0.02231	0.11536	0.16417	0.19261	0.20383	0.16968	0.13751
2021	0.07974	0.14818	0.01032	0.00478	0.05511	0.08113	0.09617	0.10249	0.08656	0.07091
2022	0.07693	0.14791	0.02093	0.00528	0.05186	0.08002	0.09609	0.10321	0.08855	0.07331
2023	0.07603	0.14677	0.02934	0.00639	0.04912	0.07879	0.0959	0.10379	0.09025	0.07551
2024	0.0749	0.14561	0.03732	0.00802	0.04661	0.07741	0.09562	0.1043	0.09186	0.07714
2025	0.07341	0.1445	0.04504	0.01013	0.04433	0.07592	0.09523	0.10476	0.09339	0.075
2026	0.07317	0.143	0.0103	0.00249	0.02123	0.0372	0.04738	0.05256	0.04737	0.04101
2027	0.06995	0.14339	0.02264	0.00323	0.01991	0.0363	0.0471	0.0528	0.04823	0.04221
2028	0.06801	0.14294	0.03302	0.00485	0.01882	0.03539	0.04677	0.05297	0.04897	0.04341
2029	0.06626	0.14221	0.04256	0.00717	0.01795	0.03446	0.04638	0.05309	0.04965	0.04451
2030	0.06524	0.14113	0.05089	0.00997	0.01736	0.03354	0.04594	0.05315	0.05024	0.04552
2031	0.06283	0.14036	0.01196	0.00271	0.0085	0.01629	0.02271	0.02658	0.02542	0.02321
2032	0.06099	0.13987	0.02422	0.00359	0.00813	0.01582	0.02244	0.02659	0.02572	0.02382
2033	0.05885	0.13918	0.03583	0.00554	0.00786	0.01535	0.02213	0.02655	0.02599	0.02423
2034	0.05739	0.13813	0.04607	0.00828	0.00779	0.0149	0.02181	0.02649	0.02622	0.02484
2035	0.05896	0.13652	0.05371	0.01121	0.00795	0.01452	0.02149	0.02641	0.02638	0.02525
2036	0.05625	0.13586	0.01271	0.00309	0.00421	0.00706	0.01056	0.01314	0.01329	0.01282
2037	0.05629	0.13486	0.0242	0.004	0.00418	0.00691	0.01039	0.01308	0.01337	0.01312
2038	0.05581	0.13387	0.03495	0.00586	0.00424	0.00677	0.01021	0.013	0.01343	0.01332

EA	EB	EC	ED	EE	EF	EG	EH	EI	EJ	EK	EL
Oa	V	YEAR	WO	WO	WO	WO	WO	WO	WO	WO	WO
654.107		2011	0.23068	0.63498	0.30433	0.5322	1.88915	1.98587	2.41316	2.43092	1.716
646.49		2012	0.22844	0.62304	0.32619	0.52478	1.82344	2.0012	2.40777	2.45556	1.780
635.843		2013	0.22355	0.61266	0.34944	0.51903	1.75792	2.0121	2.40409	2.47914	1.844
621.098		2014	0.21544	0.60452	0.37597	0.51532	1.69114	2.01899	2.40205	2.50252	1.909
605.386		2015	0.20667	0.5967	0.40231	0.51388	1.62651	2.02053	2.4009	2.52454	1.972
559.936		2016	0.20506	0.58433	0.08338	0.10257	0.78698	1.00761	1.19924	1.27061	1.011
551.744		2017	0.20076	0.57806	0.12199	0.10308	0.74859	1.00513	1.19998	1.28114	1.040
548.745		2018	0.20148	0.56916	0.15108	0.10571	0.71566	0.99962	1.1999	1.28986	1.065
544.092		2019	0.20039	0.56129	0.18023	0.11024	0.68384	0.99204	1.19952	1.29821	1.089
538.562		2020	0.19831	0.55406	0.20868	0.11661	0.65361	0.98253	1.19863	1.3061	1.112
506.771		2021	0.1942	0.54753	0.04747	0.02499	0.31227	0.48552	0.5985	0.65674	0.567
497.212		2022	0.18736	0.54656	0.09631	0.02757	0.29384	0.4789	0.598	0.66132	0.580
492.941		2023	0.18516	0.54234	0.13502	0.03339	0.27829	0.47152	0.5968	0.66504	0.591
487.956		2024	0.18242	0.53807	0.17173	0.04188	0.26407	0.4633	0.59502	0.66836	0.602
481.936		2025	0.17878	0.53394	0.20724	0.05294	0.25119	0.45435	0.59264	0.67129	0.61
461.97		2026	0.17822	0.52839	0.04738	0.01302	0.12028	0.22264	0.29483	0.3368	0.310
452.885		2027	0.17035	0.52986	0.10419	0.01687	0.1128	0.21725	0.29313	0.33832	0.316
447.266		2028	0.16564	0.52817	0.15193	0.02536	0.10664	0.2118	0.29106	0.33941	0.321
441.943		2029	0.16138	0.52549	0.19581	0.03749	0.10173	0.20621	0.28862	0.34016	0.325
438.384		2030	0.15889	0.52151	0.23418	0.05207	0.09834	0.20072	0.28587	0.34055	0.329
415.513		2031	0.15303	0.51865	0.05501	0.01416	0.04817	0.09751	0.14135	0.17035	0.166
411.284		2032	0.14853	0.51685	0.11146	0.01878	0.04605	0.09471	0.13962	0.17035	0.168
405.777		2033	0.14334	0.5143	0.16488	0.02894	0.04453	0.09188	0.13772	0.17015	0.170
402.059		2034	0.13977	0.5104	0.21198	0.04327	0.04415	0.08919	0.13572	0.16977	0.17
405.598		2035	0.14359	0.50445	0.24712	0.05858	0.04502	0.08689	0.13376	0.1692	0.172
383.256		2036	0.13699	0.50203	0.05848	0.01614	0.02383	0.04226	0.06574	0.08423	0.087
384.638		2037	0.13709	0.49832	0.11135	0.02088	0.0237	0.04137	0.06465	0.08381	0.087
384.385		2038	0.13592	0.49468	0.16081	0.0306	0.02404	0.04053	0.06354	0.08329	0.088

Stand development | Growth | Basal area, volume | Harvest | sim stand average | Sim stand data | Sim ba data | sim ba average | sim harvest avg | sim ...

Figure 7. Display of the Basal area, volume worksheet

TSI worksheet- This worksheet (Fig. 8) shows for each year, when TSI is implemented, the number of trees removed, volume harvested, and residual basal area for each species and size. All of the tables are formatted in the same way as the previous tables.



YEAR	WO	WO	WO	WO	WO	WO	WO	WO	WO	WO	WO	WO	WO	WO	WO	WO	RO	RO	RO	RO
2011	53.00294	24.24332	16.02192	13.64074	7.072619	4.854858	4.148121	3.09585	1.683062	1.063826	0.644177	0.676468	0.147887	0.101777	0.023763	0.062846	0.054905	42.52753	17.64835	11.65866	9.729
2016	47.11612	22.30962	4.389516	2.628874	2.946283	2.463304	2.061446	1.618161	0.991937	0.628024	0.390677	0.330427	0.157954	0.070055	0.026426	0.02432	0.03366	31.8334	15.86993	4.027398	2.575
2021	44.62123	20.90455	2.499281	0.640486	1.169075	1.186942	1.028803	0.836382	0.556577	0.36851	0.235244	0.175789	0.106904	0.053185	0.022639	0.012929	0.01921	26.79943	14.16643	2.438759	0.849
2026	40.9483	20.17385	2.494183	0.333712	0.4503	0.544288	0.506806	0.428923	0.304594	0.213274	0.141269	0.099308	0.065716	0.037275	0.017966	0.008736	0.011277	22.75554	12.88496	2.194873	0.474
2031	35.16085	19.802	2.896006	0.362879	0.18033	0.238375	0.242967	0.216945	0.163412	0.121159	0.08405	0.058228	0.039557	0.024492	0.013219	0.006494	0.007137	18.37465	11.87648	2.257025	0.442
2036	31.47633	19.16712	3.078801	0.413667	0.089216	0.103324	0.113011	0.107268	0.085437	0.066979	0.048837	0.034384	0.023679	0.015402	0.009034	0.004731	0.004821	16.73629	10.89356	2.249789	0.46
2041	30.28653	18.44923	3.031799	0.423064	0.059683	0.047618	0.051814	0.051794	0.043463	0.035952	0.027553	0.020028	0.014055	0.009426	0.005845	0.003264	0.003333	17.46179	10.40425	2.19591	0.472
2046	31.686	17.96328	2.935543	0.413396	0.049308	0.025516	0.024236	0.024628	0.021585	0.018779	0.015108	0.011417	0.008229	0.005663	0.003652	0.002148	0.00229	20.53136	10.61352	2.183946	0.473

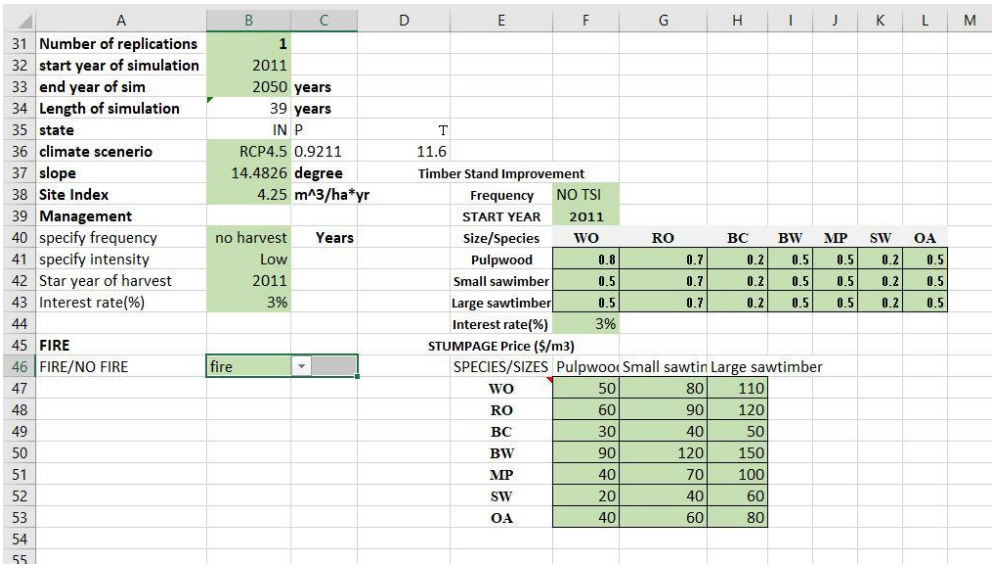
Figure 8. Display of the TSI worksheet

EXAMPLE-2: Stochastic simulations considering fire impacts

In this example, we perform simulations based on the stochastic part of the model, i.e., we choose, **Fire** = "YES" in the input section. We turn off all management-related options included in the TSI and Management sections. This example illustrates how to read the results of the stochastic growth model when requiring multiple repetitions.

Setting Simulator Parameters:

The number of repetitions is set as "10" here. "no harvest" and "no TSI" are selected as the program in its current state cannot evaluate management when performing stochastic simulations (fig.9).



	A	B	C	D	E	F	G	H	I	J	K	L	M
31	**Number of replications**	**1**											
32	**start year of simulation**	2011											
33	**end year of sim**	2050	**years**										
34	**Length of simulation**	39	**years**										
35	**state**	IN	P	T									
36	**climate scenerio**	RCP4.5	0.9211	11.6									
37	**slope**	14.4826	**degree**		**Timber Stand Improvement**								
38	**Site Index**	4.25	**m^3/ha*yr**		**Frequency**	NO TSI							
39	**Management**				**START YEAR**	**2011**							
40	specify frequency	no harvest	**Years**		**Size/Species**	**WO**	**RO**	**BC**	**BW**	**MP**	**SW**	**OA**	
41	specify intensity	Low			**Pulpwood**	**0.8**	**0.7**	**0.2**	**0.5**	**0.5**	**0.2**	**0.5**	
42	Star year of harvest	2011			**Small sawimber**	**0.5**	**0.7**	**0.2**	**0.5**	**0.5**	**0.2**	**0.5**	
43	Interest rate(%)	3%			**Large sawtimber**	**0.5**	**0.7**	**0.2**	**0.5**	**0.5**	**0.2**	**0.5**	
44					**Interest rate(%)**	3%							
45	**FIRE**				**STUMPAGE Price ($/m3)**								
46	FIRE/NO FIRE	fire			SPECIES/SIZES	Pulpwoo	Small sawtin	Large sawtimber					
47					**WO**	50	80	110					
48					**RO**	60	90	120					
49					**BC**	30	40	50					
50					**BW**	90	120	150					
51					**MP**	40	70	100					
52					**SW**	20	40	60					
53					**OA**	40	60	80					
54													
55													

Figure 9. Display of input variables within input worksheet

Simulation Output

The outputs of this example are contained in two worksheets. ***Rep stand data*** worksheet contains, for each replication, the number of trees per hectare on the stand by species and diameter class, while the

Rep ba data worksheet displays the basal area. All the data displayed follow the same format as the other data tables. The variation in each replication of the same simulation (i.e., same parameters) is due to the random fire impacts.

Literature cited:

Ma, W., J. Liang, J. R. Cumming, E. Lee, A. B. Welsh, J. v. Watson, and M. Zhou. 2016. Fundamental shifts of central hardwood forests under climate change. *Ecological Modelling*. 332:28–41.

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