ESTIMATION OF FIELD WORKDAYS IN CANADA FROM THE VERSATILE SOIL MOISTURE BUDGET

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INTRODUCTION

Synthesized agrometeorological data are often more useful than the basic climatic data used to derive such elements as evapotranspiration and soil moisture. This is especially the case where physical and biological processes, such as plant growth and development of crops, are being simulated and interpreted. Basic climatic data have been collected and provided by the Atmospheric Environment Service (AES) (formerly Canadian Meteorological Service) for approximately 1,000 stations across Canada for at least 30 yr. Sythesized agrometeorological data have been employed in studies pertaining to agricultural water needs, soil-climate interpretations, plant zonation, potential crop yield assessments, and land use evaluations. Sythesized soil moisture data from the Versatile Soil Moisture Budget (2), or similar climatological techniques, are especially useful in studies of weather conditions in relation to soil cultivation, planting, and harvest operations. Although there is also an obvious need for this type of information in agricultural engineering, there are few reported analyses of this kind to exploit the vast amount of climatic data through the use of such techniques.

Rutledge and McHardy (7) used a simplified version of the Versatile Budget for estimating work and non-workday probabilities for seven stations in Alberta with medium to heavy soils and sandy soils. They assumed a 4-inch (10.2-cm) soil moisture storage capacity distributed over the six zones of the Versatile Budget (5). They recommended as criteria for a nonworkday an estimated soil moisture content in excess of 95% of field capacity

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TABLE I CRITERIA FOR A FIELD WORKDAY BASED ON ESTIMATED SOIL MOISTURE IN THE UPPER THREE ZONES

Soil moisture notation	Zone	Depth of zone (inches)	Field capacity (F.C.) (inches)	Workday criteria: no snow on ground, % of F.C.
SM 97.5	1	0-2	0.40	≤97.5
	2	2-6	0.60	≤97.5
	3	6-10	1.00	≤97.5
SM 90/95	1	0-2	0.40	≤90.0
	2 and 3	2-10	1.60	≤95.0

in any of the three upper zones. However, the inclusion of three zones was justified only in medium or heavy soils (loam or silty clay loam). In sandy soils, only two zones warranted consideration.

This 95% level is slightly higher than the 90% level reported by Selirio (9) as criteria for days when soil cultivation in Puslinch field near Guelph, Ontario, was possible. Selirio and Brown (10), using the 90% criteria for a loam soil, related the estimated first dates of soil tractability with the actual dates of field work at Guelph from 1946 to 1968. They found a significiantly high correlation coefficient (r = 0.91). A check on their procedure with planting records from Merlin (Ontario) and climatological data for Harrow (Ontario) for 1927 to 1964 also showed that in 25 of the 38 yr the first field-work date occurred on a day estimated to be tractable. The estimated date was within 1, 2, or 3 d of the actual date in 75, 76 and 82% of all cases.

The purpose of this paper is to demonstrate the use of the Versatile Budget for estimating average and probable field workdays during selected periods based on both calender time and development stages of the wheat crop at 10 selected stations across Canada.

PROCEDURE

Soil Moisture Estimates

A climatological technique called Versatile Soil Moisture Budget (VB), as proposed by Baier and Robertson (2), was used to estimate daily soil moisture. This technique requires as input daily observed data on precipitation and daily potential evapotranspiration (PE) estimated from another earlier developed (1) and later verified (3) climatological technique. The VB simulates variations in daily soil moisture content (SM) in each of six or less zones in the soil profile. These variations are caused by precipitation, drainage, and actual evapotranspiration (AE). Instructions and computer programs for estimating daily PE, AE, and SM are based on these techniques are available (5).

In this study, a soil cropped with spring wheat every year and holding 8 inches (20.3 cm) of plant-available water in the maximum rooting zone was assumed. This amount is distributed over the six "standard" zones of the VB as defined in the instructions for the computer program (5). The depths of the three upper zones, as given in Table I, refer to a medium to heavy clay loam type of soil with a storage capacity of 2 inches (5.1 cm) within 0-10 inches (0-25.4 cm) depth.

Daily SM was estimated from the daily climatic records of precipitation and maximum and minimum air temperatures for the period 1931-60 as provided by the AES for each of the 10 selected Agriculture Canada stations at Normandin, Charlottetown, Agassiz, Ottawa, Fort Simpson, Fort Vermilion, Harrow, Brandon, Lethbridge, and Swift Current.

Definition of Field Workday

A field workday is here defined as a day with no snow cover and with estimated soil moisture conditions in the upper three zones, as shown in Table I. This definition assumes that different criteria apply to different field operations or use of farm machinery:

SM 97.5 denotes equally dry (⩽ 97.5% of field capacity) conditions in all three upper zones, as required for heavy machinery and for relatively deep cultivation (0-10 inches) (0-25.4 cm);

SM 90/95 denotes dry surface conditions (⩽ 90%) in the first zone, but somewhat wetter conditions may prevail in the second and third zones as long as the average of these zones is ⩽ 95% of field capacity. This situation would allow the use of lighter machinery or shallow soil cultivation with the 0-2-inch (0-5.1-cm) depth, but not with the 0-10-inch (0-25.4-cm) depth.

It should be noted that the critical soil moisture level of 97.5% of field capacity in an 8-inch (20.3-cm) capacity soil within the maximum rooting zone, as assumed in this study, is equivalent in water content to 95% of field capacity in a 4-inch (10.2-cm) capacity soil as used by Rutledge and Russell (8). They found in their study, which included 2 yr of checked data, that this level is a good criterion for whether or not tillage operations can be performed.

Definition of Crop Development Periods

Days that met the requirements as specified by the definition were considered as workdays and counted within calendar time periods (10 d, months, season or year) and within selected crop development periods. An average planting date (P), typical for each location, as shown in Table IV, was used in each of the 30 years under analysis. Other selected crop development stages were: emergence (E), jointing (J), heading (H), soft dough (S), and ripe (R). These dates in each of the 30 yr were computed by the Biometeorological Time Scale Model (6). Freeze-up (F) of the soil in fall was assumed as the date when the mean air temperature weighted over 5 d by a binomial smoothing technique (4) dropped below 32°F (0°C). When this temperature threshold did not occur at a location (e.g., Agassiz), January 17 was arbitrarily chosen as the end of the "ripe to freeze-up" (R-F) period.

Probabilities

Probabilities were calculated by a computer program, as described earlier, for computing risks of irrigation requirements (4). Average refers here to 50% probability assuming a normal distribution. The number of estimated field workdays, as given in the table columns under 50% or 10% probability, can be expected to be less in 5 out of 10 yr, or in 1 out of 10 yr, respectively.

TABLE II AVERAGE MONTHLY NUMBER OF WORKDAYS BASED ON SM ⩽97.5 (50% PROBABILITY)

Station	Province	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Total
Normandin	Que.	0.3	14.9	16.1	18.4	18.3	6.1	0.9	0	75.0
Charlottetown	P.E.I.	0.6	11.5	18.4	23.7	22.1	10.1	0.6	0	87.0
Agassiz	B.C.	2.2	13.1	16.3	24.4	23.9	13.0	1.7	0	94.6
Ottawa	Ont.	4.0	18.6	22.0	24.9	22.7	13.3	5.0	0.2	110.7
Fort Simpson	N.W.T.	0.9	18.9	26.2	26.9	24.2	13.0	3.3	0	113.4
Fort Vermilion	Alta.	7.0	24.6	25.9	26.5	26.3	21.5	8.7	0	140.5
Harrow	Ont.	6.6	20.8	22.9	26.6	24.9	21.7	13.2	12.8	149.5
Brandon	Man.	9.8	23.7	22.2	25.7	25.1	23.4	19.6	4.8	154.3
Lethbridge	Alta.	16.0	23.9	23.2	28.6	28.1	25.1	22.3	9.1	176.3
Swift Current	Sask.	17.1	27.2	24.0	28.0	27.9	26.0	24.5	8.2	183.2

TABLE III NUMBER OF FIELD WORKDAYS FROM MAY TO OCTOBER BASED ON SM 97.5 AND 90/95 FOR 50% AND 10% PROBABILITIES†

	SM 97.5			SM 90/95			Difference SM 90/95-SM 97.5
Station	50%	10%	Diff.	50%	10%	Diff.	50%
Normandin	75	32	44	83	42	41	+8
Charlottetown	87	47	40	96	58	38	+9
Agassiz	95	47	48	104	56	48	+9
Ottawa	111	65	46	118	73	45	+7
Fort Simpson	113	71	42	117	75	42	+4
Fort Vermilion	141	89	52	143	93	50	+2
Harrow	150	85	65	145	95	50	−5
Brandon	154	96	58	159	107	52	+5
Lethbridge	176	116	60	178	122	56	+2
Swift Current	183	131	52	185	136	49	+2

† 50% Probability: field workdays are less than the number shown in 5 out of 10 yr;
10% probability: field workdays are less than the number shown in 1 out of 10 yr.

RESULTS

Table II presents the average number of workdays by month for SM ⩽ 97.5 at the 10 selected stations. The Prairie stations and Harrow experience a greater number of field workdays, especially in spring and fall, than all other locations. Less than 100 workdays per year occur on the average at Normandin, Charlottetown, and Agassiz, more than 150 workdays at Harrow, Brandon, Lethbridge, and Swift Current, and between 100 and 150 workdays at Ottawa, Fort Simpson, and Fort Vermilion. The workday distribution across Canada for SM 90/95 is similar, but with this moisture criterion there are generally 4-9 additional d available in the humid areas and 2 additional d on the Prairies (Table III). Harrow is an exception, because it has fewer workdays in November as defined by SM 90/95 (2 d) as compared with SM 97.5 (13 d). Table III also gives for both moisture criteria the difference in days that can be expected when planning is based on 50% or 10% probabilities.

Figure 1 illustrates for three selected stations the average number of workdays during each 10-d period from April 1 to November 30. The advantage of the climate at Swift Current for field operations is striking as compared with the conditions at Fort Simpson and Charlottetown in both spring and fall.

Farming operations are normally not scheduled according to calendar periods but rather according to weather, soil conditions, and crop development stages. Table IV summarizes average workdays per "crop periods" extending from one crop development stage to the next, as defined under "Procedure." Table IV is particularly useful for comparing climates in terms of the number of workdays during crop periods in relation to the time in days, that is, on the average available for field work during these periods. For example, the period from ripe to freeze-up is 67 d at Normandin, of which only 8.4 d are workdays. On the other hand, the average R-F period at Swift Current is 87 d, of which 74.3 d are workdays.

TABLE IV AVERAGE NUMBER OF FIELD WORKDAYS FOR WHEAT CROP PERIODS BASED ON SM 97.5

Station	Assumed planting date	Avg length of period†						Avg no. of workdays							
		P-E	E-J	J-H	H-S	S-R	R-F	21 d before P	P-E	E-J	J-H	H-S	S-R	R-F	Total
Normandin	May 23	9	21	25	29	15	67	9.7	4.8	11.2	14.9	17.5	7.8	8.4	74.3
Charlottetown	May 17	9	21	24	26	9	106	4.6	4.5	11.9	16.8	21.0	7.2	21.1	87.1
Agassiz	Apr. 11	10	26	31	26	12	153	0.1	0.4	7.3	16.1	17.1	10.1	44.1	95.2
Ottawa	May 10	8	22	22	22	9	109	8.4	5.2	14.8	16.4	17.8	8.2	39.8	111.6
Fort Simpson	May 23	9	15	24	22	20	52	11.8	7.3	13.1	22.0	18.7	15.5	23.0	111.4
Fort Vermilion	May 13	9	21	27	22	19	64	14.1	7.1	18.4	22.1	18.6	16.5	40.2	137.0
Harrow	Apr. 19	9	26	23	21	8	137	2.6	3.3	16.6	18.1	17.6	7.4	72.3	137.9
Brandon	May 5	10	24	24	20	11	91	11.2	7.8	18.4	18.8	17.1	10.2	65.3	148.8
Lethbridge	Apr. 21	13	27	30	21	12	94	10.0	7.3	22.2	23.8	19.5	11.5	74.8	169.1
Swift Current	Apr. 25	12	27	28	21	12	87	12.5	8.5	25.0	22.9	18.9	11.4	74.3	173.5

† P = planting; E = emergence; J = jointing; H = heading; S = soft dough; R = ripe; F = freeze-up. See Robertson (6).

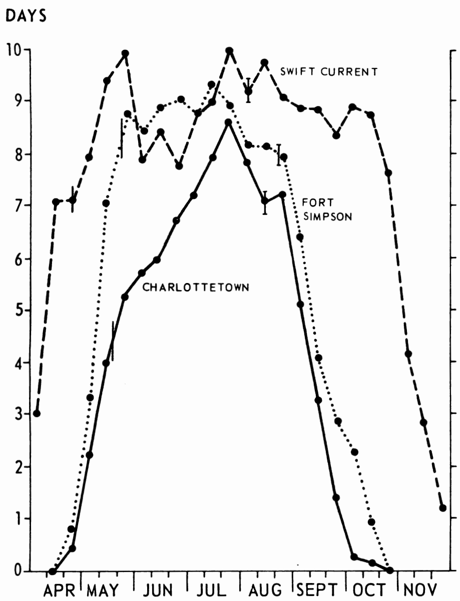

Figure 1. Average (50% probability) number of workdays based on SM 97.5 for each 10-d period from April to November at three selected stations. Average spring planting date (vertical bar left of center): April 25, Swift Current; May 17, Fort Simpson; May 23, Charlottetown. Average ripening date (vertical bar right of center): August 5, Swift Current; August 16, Charlottetown; August 22, Fort Simpson.

Assuming that the dates for the selected 10 sites are characteristic for the climatic region in which these stations are located, the approximate number of field workdays from 21 d before planting (P) to freeze-up (F) is then less than 100 in Québec, British Columbia, and Prince Edward Island; it gradually increases over Canada from east to west and from north to south to over 150 d on the Prairies with a maximum of 173.5 d in southern Saskatchewan.

DISCUSSION AND CONCLUSIONS

The results should be considered only as a demonstration of the potential use of climatological techniques for estimating field workday probabilities from standard climatic data. Care should be taken in the interpretation of the data, because they depend on the validity of several assumptions and on the criteria as specified by the soil moisture definition. Some of the results may merely confirm accepted experience. It is, however, now possible by means of the proposed estimating techniques to express various soil and climatic interactions in terms of workday probabilities. The averages and variations of the time available for field work should be more useful for planning farming operations and machinery size than the standard climatic data from which this information was derived.

Future research and applications should include the development and perfection of a planting date estimator for various crops and soils, as suggested by Selirio and Brown (10). The estimates obtained from the techniques as described in this paper should be verified against field observations.

From these techniques and the necessary long-term daily climatic data, which are available for approximately 1,000 stations across Canada from the AES, it should be possible to compute a more detailed analysis specifically designed for local climates, soils, and farming practices. On the other hand, a country-wide analysis of field workdays for "standardized" soils and farming practices but accounting for variations due to climates has also practical applications in agricultural engineering. Research is in progress to analyze the frequency of consecutive field workdays through a Markov chain probability program especially developed for this type of data.

SUMMARY

The approach of using estimates from the Versatile Soil Moisture Budget as a basis for determining the number of field workdays has been outlined. Daily climatic records for the 1931-60 period at 10 selected stations across Canada were analyzed for this purpose. Because of climatic variations among these locations, the number of field workdays from April to November for a "standardized" soil varied from 75 at Normandin, Québec to 183 at Swift Current, Saskatchewan. Workdays for crop periods, based on the computed development stages of a wheat crop during each of the 30 seasons, showed that on the average at Normandin, only 8 days of the period from ripe to freeze-up were actual workdays as compared with 74 days for the same period at Swift Current. A country-wide analysis of field workdays is suggested, subject to verification of several assumptions in this study. These statistics provide useful information for scheduling farming operations, planning farm machinery size, and for research and services by agricultural engineers.

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