Computer Prediction of Suitable Workdays for Mechanized Winter Wheat Operations in Chile

by
Edmundo J. Hetz
Associate Professor
Agric. Engg. Dept.
University of Concepcion
Chillan, Chile

Arthur Gold
Instructor
Agricultural Engg. Dept.
Michigan Stage University
East Lansing, MI 48824, U.S.A.

Luke E. Reese
Graduate Student
Agric. Engg. Dept.
Michigan State Univ.
East Lansing, MI 48824, U.S.A.

Abstract

Suitable workdays for winter wheat operations in south central Chile are presented over a range of probability levels. Predictions are generated from a computer model which simulates daily soil moisture using 17 years of daily weather records. Results show that few suitable workdays are available during seeding (May-June), demanding a careful approach to the selection and scheduling of planting equipment.

Introduction

Machinery management decisions are among the most important that farmers make in today's agriculture. Their importance stems from the long-term effect they have and the high proportion of total production costs incurred by farm machinery. These decisions are extremely important in Chile, where farmers have to compete for the international grain market, and where the purchase price of farm equipment and fuel is approximately double the price that a farmer pays in the USA (Hetz, 1982). The need for proper machinery selection becomes even more important when one considers the cost of owning and operating a typical farm tractor which increased by 100% from the spring of 1977 to the fall of 1980 (Mayfield, *et al.*, 1981), while the farm price of wheat has remained fairly stable (FAO, 1981).

The selection of agricultural equipment and scheduling their use depends primarily upon the ability to predict available working time for field operations during the cropping season. Numerous studies have been carried out to meet the widely recognized requirement for this type of information which is readily available for the major agricultural regions of the USA, Canada and Europe (i.e., ASAE, 1982; Baier, 1973; Van Kampen, 1971). In most developing countries, particularly in Chile, this kind of data is sorely missing.

Records of days suitable for fieldwork, like the ones reported by Morey, *et al.* (1971), and Fulton, *et al.* (1976) have not been kept in Chile. Suitable days for fieldwork can be predicted with reasonable accuracy in developing countries by computer models that use long-term climatological records. Models for agricultural areas in the USA and Canada have been reported in the literature (Dyer and Baier, 1979; Frisby, 1970; Hassan and Broughton, 1975; Nath and Johnson, 1980; Rutledge and McHardy, 1968; Selirio and Brown, 1972; Shaw, 1965).

This paper presents estimates of the number of days suitable for winter wheat operations at selected probability levels. Predictions are generated from a computer model which simulates daily soil moisture using 17 years of daily weather records. Parameters used in this model are: precipitation, pan evaporation, and hours of sunshine. In regions where pan evaporation records do not exist, Penman's modified equation (Merva and Fernandez, 1982) might be used to generate evapotranspiration data from standard meteorological data.

The Study Area

The Province of Nuble is an important agricultural area of south central Chile. In the eastern part of this province and the adjacent Bio-Bio Province there are approximately 500,000 ha of low rolling hills. Nearly 250,000 ha in this Andes Pre-Cordillera region are used to produce wheat, oats, barley, lentils, rapeseed, and pasture (INIA, 1980). Wheat and other small grain cereals account for 80% of the area planted with annual crops in Chile.

The soils in this area have developed from recent deposits of volacnic ashes (Dystrandept) and they have been grouped in the Santa Barbara series. The soils are a deep well drained loam (49% sand, 31% silt, 20% clay), brown to dark gray in color, and a topography with 8 to 12% slope. Bulk density is 0.65 g/cc and the total porosity is 75%. The soils are highly permeable with a basic infiltration rate of 5.0 cm/h, having a total organic matter content of 16%, and a high plastic limit (Bernier, 1966; Pena, 1978; Mellado, 1981). The trafficability zone extends to high moisture contents due to the high plastic limit (Duarte, 1982).

This Andes Pre-Cordillera area has a temperature Mediterranean climate, with 1 to 3 dry months and over 4.5 frost-free months. The average annual rainfall and average winter rainfall are 1 305 and 760 mm, respectively (Pena, 1978).

Winter wheat and oats, which are by far the most important crops in the area, should be seeded between May 15 and June 15 (INIA, 1980). As shown in **Fig. 1**, this is also the rainiest part of the year, thus creating many difficulties to finish machinery operations on time.

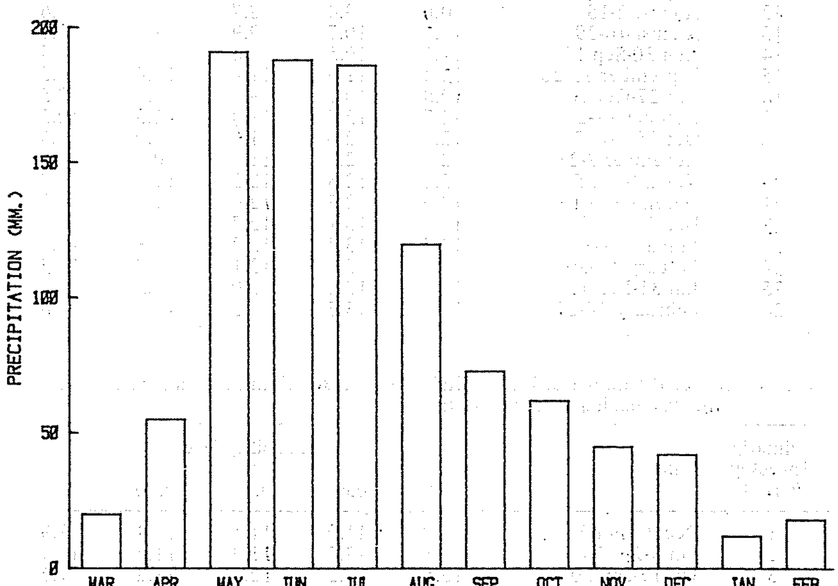

Fig. 1 Monthly rainfall distribution.

Methods

The computer model generates estimates of daily soil moisture in the top 150 mm of the soil and then determines if field operations are possible (Shaw, 1965; Nath and Johnson, 1980; Selirio and Brown, 1972). The model is based on 17 years of daily records of precipitation, pan evaporation, and hours of sunshine collected at the Agro-meteorological Station of the University of Concepcion, Chillan, Chile. In addition, the model requires crop and soil characteristics, along with the time of year.

Soil moisture (SM) in the top 150 mm for day (t) was calculated by the following equation:

$$SM(t) = SM(t-1) + Infiltration(t) - Evapotranspiration(t) - Drainage(t)$$

Soil moisture was initialized at Permanent Wilting Point at the start of each computational year (March 1), since January and February are consistently hot and dry. Infiltration was calculated whenever precipitation occurred on day(t) and the soil moisture content was below saturation. Based on the findings of Mellado (1981), infiltration was assumed to be 0.9 of precipitation until saturation is reached. Daily evapotranspiration was based on daily evaporation from a U.S. Weather Bureau Class A pan. Coefficients for crop stage (Pair, *et al.,* 1976; Tulu, 1974), and root distribution throughout the root zone (Baier and Robertson, 1966) were employed to yield actual evapotranspiration in the top 150 mm of the soil. Evapotranspiration was assumed to be zero when the soil moisture content was at Permanent Wilting Point. Whenever the soil moisture was greater than field capacity a drainage quantity was calculated for use in the moisture budget of the following day. It was assumed that the soil would drain to field capacity two days after a saturating rain (Hassan and Broughton, 1975).

Once soil moisture was computed, a set of criteria was used to determine if conditions were suitable for soil engaging, above ground and cereal harvesting machinery operations.

A suitable day for soil engaging operations had to meet the following criteria:

(a) soil moisture less than 99% of Available Water Capacity (Rutledge and McHardy, 1968);
(b) less than mm precipitation on the day in question (Frisby, 1970).

A suitable working day for above ground operations requires:

(a) less than 2 mm precipitation;
(b) soil moisture of previous day less than saturation (Hunt, 1980; Frisby, 1970).

A suitable day for cereal harvesting met all the following criteria (Von Bargen, 1966; van Kampen, 1971):

(a) less than 2 mm precipitation;
(b) eight or more hours of sunsine (unless soil moisture was at Permanent Wilting Point);
(c) soil moisture less than saturation;
(d) less than 12 mm precipitation on the previous day.

After the weather records were transformed into suitable and non-suitable workdays, estimates of the minimum number of suitable days at selected probability levels were derived using empirical cumulative probability distributions (Rosenberg, *et al.*, 1981). The only data available to compare with the computer predictions came from a survey of farmers carried out by Hetz (1982). Farmers were asked to estimate the average number of days suitable for soil engaging operations for half-months periods, between April 1 and September 30.

Results and Discussion

Tables 1, 2, and **3** depict the expected minimum number of days suitable for different operations at selected probability levels. Since most farm operations occur over at least a two-week period, biweekly values are presented. **Table 4** depicts a comparison between the results of the farmer's survey and the model output at design probability levels of 0.60, 0.70, and 0.80.

The opinions of surveyed farmers were matched most closely by the 0.7 probability level. For 10 of the 12 biweekly periods the 0.70 design probability values were found to be within 10% of the farmers' estimates ($r = 0.91$). Dis-

Table 1 Expected Number of Days Suitable for Fieldwork in Eastern Nuble Province, Chile. (Cereal harvesting operations).

Climatic Biweekly Period	Date	Probability level				
		0.50	0.60	0.70	0.80	0.90
1	March 1-14	13.3	13.0	12.7	12.4	12.1
2	March 15-28	13.4	13.2	12.8	12.3	10.6
3	Mar 29-Apr 11	13.1	12.7	12.2	11.6	10.6
4	April 12-25	11.6	10.9	10.3	9.6	8.6
5	Apr 26-May 9	11.2	10.5	9.4	8.1	4.8
6	May 10-23	7.0	6.1	5.5	4.8	3.8
7	May 24-June 6	8.2	7.6	6.9	5.1	0.8
8	June 7-20	7.4	6.9	6.3	5.1	3.1
9	June 21-July 4	6.8	6.2	5.6	5.0	2.6
10	July 5-18	8.1	7.6	6.9	5.6	3.8
11	July 19-August 1	8.0	7.1	5.9	4.6	1.8
12	August 2-15	9.1	8.1	7.5	6.4	3.5
13	August 16-29	11.2	10.5	9.4	7.6,	6.4
14	Aug 30-Sep 12	11.0	10.1	9.0	8.1	6.8
15	September 13-26	12.3	11.7	11.1	10.3	6.6
16	Sep 27-Oct 10	10.4	9.7	9.0	8.2	7.4
17	October 11-24	12.4	11.9	11.5	11.1	10.4
18	Oct 25-Nov 7	12.3	11.9	11.4	10.6	8.8
19	November 8-21	12.7	12.2	11.5	10.1	8.5
20	Nov 22-Dec 5	13.0	12.6	12.2	11.3	9.8
21	December 6-19	12.9	12.3	11.8	11.2	9.8
22	Dec 20-Jan 2	13.4	13.1	12.6	12.0	11.2
23	January 3-16	13.7	13.4	13.2	12.8	12.1
24	January 17-30	13.5	13.2	13.0	12.2	11.2
25	Jan 31-Feb 13	13.5	13.2	13.0	12.5	11.8
26	February 14-27	13.7	13.5	13.2	13.0	11.6

Table 2 Expected Number of Days Suitable for Fieldwork in Eastern Nuble Province, Chile. (Above ground operations)

Climatic Biweekly Period	Date	Probability level				
		0.50	0.60	0.70	0.80	0.90
1	March 1-14	13.3	13.0	12.7	12.4	12.1
2	March 15-28	13.4	13.2	12.8	12.3	11.5
3	Mar 29-Apr 11	13.2	12.8	12.3	11.6	10.6
4	April 12-25	11.9	11.3	10.8	10.0	8.6
5	April 26-Mary 9	11.6	10.9	10.3	9.6	8.1
6	May 10-23	9.1	8.6	8.1	6.7	5.1
7	May 24-June 6	10.5	9.7	7.9	6.6	4.1
8	June 7-20	8.6	8.1	7.5	6.8	5.8
9	June 21-July 4	9.0	7.9	7.0	6.4	5.8
10	July 5-18	9.8	9.1	8.4	6.8	4.8
11	July 19-August 1	8.5	7.7	6.9	5.1	4.2
12	August 2-15	10.0	9.4	8.7	7.6	4.6
13	August 16-29	11.3	10.7	9.9	8.1	6.3
14	Aug 30-Sep 12	11.1	10.5	9.6	8.6	7.5
15	September 13-26	12.4	11.9	11.4	10.4	7.5
16	Sep 27-Oct 10	10.8	10.1	9.4	8.6	7.5
17	October 11-24	12.7	12.3	11.8	11.3	10.5
18	Oct 25-Nov 7	12.4	12.0	11.5	11.0	9.6
19	November 8-21	12.8	12.3	11.7	10.6	8.8
20	Nov 22-Dec 5	13.0	12.6	12.2	11.3	9.8
21	December 6-19	13.0	12.5	12.0	11.2	9.8
22	Dec 20-Jan 2	13.4	13.1	12.7	12.3	11.8
23	January 3-16	13.7	13.4	13.2	12.8	12.1
24	January 17-30	13.6	13.3	13.1	12.3	11.2
25	Jan 31-Feb 13	13.5	13.2	13.0	12.5	11.8
26	February 14-27	13.7	13.5	13.2	13.0	11.6

Table 3 Expected Number of Days Suitable for Fieldwork in Eastern Nuble Province, Chile. (Cereal harvesting operations).

Climatic Biweekly Period	Date	Probability level				
		0.50	0.60	0.70	0.80	0.90
1	Dec 20-Jan 2	13.0	11.9	11.1	10.4	8.9
2	Jan 3-Jan 16	13.1	12.5	11.9	11.4	10.9
3	Jan 17-Jan 30	13.5	13.2	12.7	11.2	7.9
4	Jan 31-Feb 13	13.3	12.9	12.2	10.5	8.7

Table 4 Comparison of Farmers' Survey and Model Results for Expected Number of Days Suitable for Soil Engaging Operations in Eastern Nuble Province, Chile.

Climatic Biweekly Period	Farmers' Survey	Model results at probability level:		
		0.60	0.70	0.80
March 29-April 11	---	12.7	12.2	11.6
April 12-25	10.9	10.9	10.3	9.6
April 26-May 9	9.4	10.5	9.4	8.1
May 10-23	7.6	6.1	5.5	4.8
May 24-June 6	6.7	7.6	6.9	5.1
June 7-20	6.2	6.9	6.3	5.1
June 21-July 4	5.9	6.2	5.6	5.0
July 5-18	5.8	7.6	6.9	5.6
July 19-August 1	5.7	7.1	5.9	4.6
August 2-15	7.2	8.1	7.5	6.4
August 16-29	8.9	10.5	9.4	7.6
August 30-Sep 12	9.4	10.1	9.0	8.1
September 13-26	10.4	11.7	11.1	10.3
September 27-Oct 10	---	9.7	9.0	8.2
Number of periods within 10% of survey results	---	4	10	2

crepancy in some periods may be due to the transfer of values from the original half-months of the survey to the biweekly periods of the model (Fulton, *et al.*, 1976). In addition, the survey was based on farmers' memory on long-term weather patterns, whereas the model uses daily records over the 17-year period.

Fig. 2 depicts a comparison between the expected number of field workdays for above ground, soil engaging, and cereal harvesting operations at the 0.80 design probability level.

Soil engaging operations include tillage and seeding, while above ground operations include spraying and fertilizer broadcasting. The values for soil engaging and above ground operations follow very closely the opposite pattern of the rainfall distribution which is shown in **Fig. 1**. **Fig. 2** also shows that there is a fairly large span of time available for fieldwork, except during the months of May, June, July, and August. This last fact should be carefully considered in the selection and scheduling of equipment used in tillage and seeding of winter and spring cereals.

Because the number of suitable field workdays varies from year to year, estimates of the minimum number available at different probability or certainty levels are required. Fulton, *et al.* (1976), suggested that for operations where failure to complete the work on time means only inconvenience or slight reductions in yield, a probability level of 0.50 might be acceptable. Such an operation might be applying fertilizer to pastures. Where timeliness is important for maximum yields, such as cereal seeding, most farmers would probably accept a probability of 0.70, but where failure to complete an operation becomes costly due to yield reduction, a probability level of 0.80 or higher is desirable. Such an operation might be cereal harvesting in Chile.

An example will illustrate the usefulness of suitable working days information. Assume a farmer who seeds 75 ha of wheat yearly is considering the purchase of a grain drill. The farmer expects to work 10 h a day and seeds between May 24 and June 6. From **Table 1** he selects 6.9 days as the minimum number of days suitable for fieldwork that he can expect 7 years out of 10 during that period. To complete the job in the allocated time, the farmer requires a minimum seeding capacity of 1.08 ha/h (75 ha divided by 69 h). Considering a work speed of 7.0 km/h and a 65% field efficiency he requires a minimum grain drill width of 2.37 m. As most of the grain drills in Chile have rows separated 0.18 m (7 in), a farmer there should select a 13-row seeder.

Conclusion

Model results show that there is sufficient time to complete most fieldwork for wheat production in the eastern part of the Province of

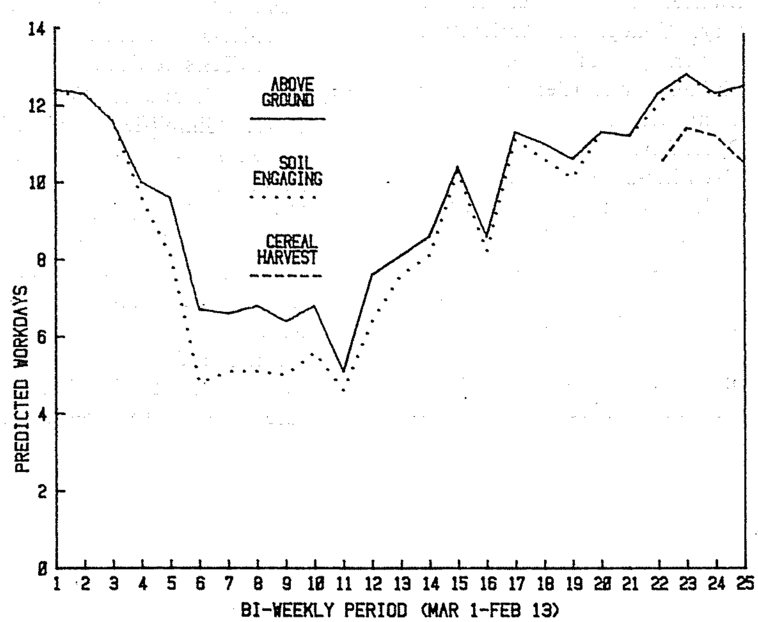

Fig. 2 Predicted suitable days, 0.8 probability level.

Ñuble, Chile. The results also show that at wheat, oats, and lentils seeding time (May-June), the expected number of days suitable for fieldwork is greatly reduced. This creates the need for a careful approach to the selection and scheduling of agricultural equipment in order to finish field operations on time. Model results at the 0.70 design probability level agree fairly well with the farmers' estimation of days suitable for fieldwork. It would, however, be very useful to set up a network of field observers and rain gauges to collect actual data on fieldwork days.

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