EPIC model parameters for cereal, oilseed, and forage crops in the northern Great Plains region

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[1]*USDA, Agricultural Research Service, Temple, TX 76503;* [2]*Agriculture and Agri-Food Canada Research Station, Lethbridge, Alberta, Canada T1J 4B1;* [3]*University of Edmonton, Edmonton, Alberta, Canada T6G 2E3;* [4]*Iowa State University, Ames, IA 50011;* [5]*Agriculture and Agri-Food Canada Research Station, Central Experimental Farm, Ottawa, Ontario, Canada K1A 0C6;* [6]*USDA, Natural Resources Conservation Service, Billings, MT 59715; and* [7]*Agriculture and Agri-Food Canada Research Station, Swift Current, Saskatchewan, Canada S9H 3X2.* *Received 29 September 1994, accepted 15 March 1995.*

Kiniry, J. R., Major, D. J., Izaurralde, R. C., Williams, J. R., Gassman, P. W., Morrison, M., Bergentine, R. and Zentner, R. P. 1995. **EPIC model parameters for cereal, oilseed, and forage crops in the northern Great Plains region**. Can. J. Plant Sci. **75**: 679–688. The EPIC computer simulation model has potential for assessing agricultural management scenarios in the northern Great Plains region of the United States and western Canada. The objectives of this study were to develop parameters for economically important crop and forage species grown in these regions and to determine whether EPIC could use these parameters to reasonably simulate yields. Parameters for leaf-area development, temperature responses, biomass growth and partitioning, and nutrient concentrations were derived from data in the literature for spring canola, wheat, barley, maize and six forage species. Because of the growing importance of canola in Canada and the United States, much emphasis was placed on deriving its parameters. With these inputs, EPIC reasonably simulated forage and crop yields in six locations and canola yields in four locations. The model should provide reasonable simulations for a wide range of applications throughout these regions.

Key words: simulation modeling, canola, agricultural management

Kiniry, J. R., Major, D. J., Izaurralde, R. C., Williams, J. R., Gassman, P. W., Morrison, M., Bergentine, R. et Zentner, R. P. 1995. **Paramètres du modèle EPIC pour les céréales, les oléagineux et les plantes fourragères du nord de la Grande Plaine**. Can. J. Plant Sci. **75**: 679–688. Le modèle de simulation EPIC est capable d'évaluer différentes pratiques culturales dans la partie nord de la grande plaine des États-Unis et dans la région ouest du Canada. L'objectif de cette étude est d'adapter les paramètres d'EPIC aux conditions de ces régions pour les cultures et les espèces fourragères qui ont une importance économique et déterminer si EPIC peut raisonnablement simuler le rendement. Les paramètres qui permettent de simuler le développement foliaire, l'influence de la température, la croissance en biomasse et sa répartition, ainsi que la concentration en minéraux, ont été obtenus pour le colza de printemps, le blé, l'orge, le maïs et six espèces fourragères à partir de données publiées. En raison de l'importance croissante du colza au Canada et aux États-Unis, l'attention a été plus particulièrement portée sur l'obtention des paramètres relatifs à cette culture. Avec ces données, EPIC a simulé de façon satisfaisante la production fourragère et les rendements en graines dans six endroits différents et le rendement en graine du colza dans quatre situations géographiques. Le modèle devrait permettre une simulation satisfaisante pour une large gamme de conditions culturales dans ces régions.

Mots clés: Simulation, colza, méthode culturale

There is increasing concern about the impact of soil degradation on soil productivity in the northern Great Plains of western Canada and the United States. Major soil degradation problems observed in the region are wind and water erosion, salination, and organic matter depletion (Prairie Farm Rehabilitation Administration 1990). Interest is growing in applying simulation models for conditions representative of the northern Great Plains, to better assess soil degradation with different crop rotations and management practices. One of these simulation models is EPIC, which computes effects of management decisions on water quality and long-term soil productivity by quantifying relationships between crop yield and erosion, productivity, and fertilizer needs (Williams 1990; Williams et al. 1990).

The EPIC model has components for weather, hydrology, erosion, nutrient cycling, soil temperature, crop growth, tillage, pesticide fate, and economics. The generic crop-growth subroutine in EPIC (Williams et al. 1989) facilitates the simulation of complex rotations and fallow-cropping systems, making the model useful for evaluating alternative crop management scenarios in the northern Great Plains

Abbreviations: DLAI, fraction of the growing season when LAI begins to decline; **DLAP1**, defines a point on the LAI development curve early in the season; **DLAP2**, identical to DLAP2, except it defines a point near anthesis; **DMLA**, potential leaf-area index; **EPIC**, Erosion–Productivity Impact Calculator; **GDD**, growing degree–days; **HI**, harvest index (the dry weight of seed divided by the total above-ground dry weight); **LAI**, leaf-area index; **PHU**, GDD from planting to maturity; **RBMD**, rate of decline in WA after LAI starts to decline; **RDMX**, potential rooting depth; **RLAD**, rate of leaf-area index decline (same function as RBMD); **TB**, optimum temperature; **TG**, base temperature; **WA**, radiation-use efficiency; **WSYF**, water stress yield factor

(Moulin and Beckie 1993). A variety of scenarios can be simulated with the model, such as evaluating the effects of managing crop rotations to avoid or minimize saline seeps in Montana or the choice of cropping systems that minimize wind erosion in the semi-arid regions of Canada.

A critical step in constructing cropping system scenarios for EPIC is the development of parameters for the crop-growth subroutine. The objectives of this study were to derive parameters for several common grain and forage species in the northern Great Plains and to determine whether EPIC reasonably simulates crop production in this region with these parameters.

MATERIALS AND METHODS

The plant species simulated in this study are economically important crops for the region. These include spring and winter wheat (*Triticum aestivum* L.), spring barley (*Hordeum vulgare* L.) and corn (*Zea mays* L.). For spring canola, both Polish (*Brassica campestris*) and Argentine (*Brassica napus*) types were investigated. Forage species included crested wheatgrass [*Agropyron cristatum* (L.) Gaertner], western wheatgrass [*Pascopyrum smithii* (Rydb.) Gould], meadow bromegrass (*Bromus biebersteinii* Roemer & Schultes), smooth bromegrass (*Bromus inermis* Leysser), Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski] and Altai wildrye [*Leymus angustus* (Trin.) Pilger].

Parameters estimated were related to 1) leaf-area development; 2) development-rate response to temperature; 3) radiation-use efficiency and physical descriptions; and 4) nitrogen and phosphorus concentrations in plant biomass.

Parameter values were generally derived from previously published research, with minimal adjustment after comparing output with crop-production data sets from a large number of published studies.

Leaf Area Development

POTENTIAL LEAF-AREA INDEX. With the exception of corn, DMLA values ranged from 3 to 5 (Table 1). The 6.5 value for corn is from the results of Tollenaar (1983) at Guelph, Ontario. Wheat, barley, and most forages were simulated using 5.0 for DMLA. Tollenaar (1983) reported a value of 5.0 for wheat. Smooth bromegrass in an irrigated field study at Mead, Nebraska, had 5.2 in 1981 (Engel et al. 1987), but we assumed dryland bromegrass has a shorter duration of growth and thus a lower DMLA of 3.0

Canola DMLA values were greater for the Argentine type than for the Polish type. Reported values for Argentine were 3.0 in Australia (Thurling 1974), 3.4 in Japan (Inanaga and Kumra 1974), 3.7 in Germany (Grosse et al. 1992), 4.5 in Britain and Wales (Allen et al. 1971; Allen and Morgan 1972; Mendham et al. 1981; Jenkins and Leitch 1986), and 5.5 under irrigation in Alberta (Major 1977). Major (1977) reported a value of 3.5 for Polish in Alberta.

Table 1. EPIC input parameters for simulating leaf area development[z]

	DMLA	DLAP1	DLAP2	DLAI	RLAD
Spring wheat	5	20.1	49.95	0.58	1
Winter wheat	5	5.05	45.95	0.5	0.5
Spring barley	5	15.01	45.95	0.6	1
Argentine canola	4.5	15.02	45.95	0.5	0.15
Polish canola	3.5	15.02	45.95	0.5	0.15
Corn	6.5	15.05	50.95	0.7	1
Crested wheatgrass	5	35.02	62.95	0.85	2
Western wheatgrass	5	50.02	89.95	0.85	2
Meadow bromegrass	3	45.02	80.95	0.85	2
Russian wildrye	3	35.02	62.95	0.8	1
Altai wildrye	3	35.02	62.95	0.8	1

[z] DMLA is the potential leaf-area index (LAI). DLAP1 and DLAP2 describe the pattern of leaf-area development prior to anthesis. DLAI defines the fraction of the season when maximum LAI occurs and when LAI can begin to decrease. RLAD defines the shape of the LAI curve after DLAI is reached.

LAI PRIOR TO FLOWERING. Two parameters describe the development of LAI prior to flowering, under non-stress conditions (Table 1). Parameter DLAP1 defines a point on the LAI development curve early in the growing season, and DLAP2 defines a point near anthesis. The value to the left of the decimal point represents a percentage of total GDD for the season, while the number to the right is the percentage of final LAI attained at this stage, in the absence of stress. Perennial forages have relatively slow LAI development. Row-crop species have 95% of their final LAI sometime between 45 and 50% of the total GDD. Perennial forages reach 95% of final LAI much later in the season, allowing for lower LAI during the establishment year. The two points on the LAI curve for canola are 15.02 and 45.95 (R. C. Izaurralde and M. C. Quiroga Jakas, pers. commun.).

To facilitate simulation of rapid growth in the spring, winter cereals have values of 5.05 and 45.95. These are from winter wheat results at Mandan, North Dakota (Garcia et al. 1988) and at Culbertson, Montana (Aase 1978). Comparable spring wheat values are 20.10 and 49.95, from Mandan (Bauer et al. 1984, 1985, 1987).

LAI LATE IN THE GROWING SEASON. Two parameters describe the decrease in LAI late in the growing season (DLAI, RLAD). The fraction of the growing season when the LAI begins to decline (DLAI) is 0.50 for spring canola and winter wheat and 0.58 for spring wheat and spring barley (Table 1). The LAI of canola and wheat starts to decrease shortly after flowering or shortly after reaching maximum LAI. Morrison et al. (1989) reported that 0.498 of the total GDD from sowing to maturity of canola had accumulated at flowering of canola. The DLAI value for winter wheat was based on the sources cited above for DMLA. The DLAI value for spring wheat was from Bauer et al. (1984, 1985, 1987) and the Saskatchewan Agricultural Services Coordinating Committee (1987).

Parameter RLAD is the LAI decline-rate factor, with values ranging from 0.15 for plants with slow leaf senescence to 2.0 for rapid senescence. A value of 1.0 causes LAI to decrease linearly to zero from date of DLAI to date of maturity.

Whereas LAI of canola declines during pod filling, the pod area index reduces the rate of decrease in the area of the plant intercepting light and photosynthesizing. When both LAI and pod area index are combined, the RLAD value of 0.15 for canola (M. J. Morrison, pers. commun.) is reasonable for simulating the decrease after flowering reported by Inanaga and Kumra (1974).

Temperature Responses

BASE TEMPERATURE FOR GROWTH AND DEVELOPMENT. Base temperature (TG, °C), the temperature below which development ceases, is critical for determining initiation of plant growth in the spring and for accurate prediction of duration of the season. Wheat, barley, and wildrye species have the lowest TG values (Kiniry et al. 1991) (Table 2), and canola (Morrison et al. 1989) has an intermediate value. Warm-season grasses and corn have the highest values. According to Saskatchewan Agricultural Services Co-ordinating Committee (1987), base temperatures are 0°C for wheat and 1.5°C for spring barley. We used a value of 0°C for both species (Kiniry et al. 1991).

OPTIMUM TEMPERATURE FOR GROWTH. Optimum temperature (TB, °C) (Table 2), the temperature at which development rate and growth rate are greatest, defines responses during the hottest portion of the season. Species with higher TB values could produce more biomass on hot days than those with lower TB values. As with TG, the lowest TB values are for wheat, wildrye, and clover, and the highest are for corn, wheatgrass species, and bromegrass. The TB value for canola, 21°C, was recommended by R. C. Izaurralde (pers. commun.) and supported by the range given by Morrison et al. (1989).

Table 2. EPIC input parameters for simulating temperature responses[z]

	TG (C°)	TB (C°)	PHU	FRST1	FRST2
Spring wheat	0	18	1500–1700	5.001	15.01
Winter wheat	0	18	1800	15.05	30.1
Spring barley	0	25	1570	5.001	15.01
Argentine canola	5	21	1000–1200[y]	5.05	15.1
Polish canola	5	21	910–1015[y]	5.05	15.1
Corn	8	25	950	5.15	15.95
Crested wheatgrass	6	25	1000–1350	5.01	15.95
Western wheatgrass	6	25	1100	5.01	15.95
Meadow bromegrass	6	25	1050	5.01	15.95
Russian wildrye	0	15	1400	5.001	15.01
Altai wildrye	0	15	1400	5.001	15.01

[z] TG is the base temperature, and TB is the optimum temperature for growing degree-day calculation. PHU is the growing degree-days from planting to maturity. FRST1 and FRST2 define how LAI is lost as a result of frost damage.
[y] Both types of canola had 800 for PHU in the Peace River region.

Table 3. EPIC input parameters related to plant dry matter partitioning[z]

	WA (kg ha^{-1} MJ^{-1} m^2)	RBMD	HI	RDMX (m)
Spring wheat	28	1	0.42	1.3
Winter wheat	30	1	0.4	1.3
Spring barley	35	1	0.54	1.3
Argentine canola	34	0.3	0.3	1.4
Polish canola	34	0.3	0.23	0.9
Corn	40	1	0.55	2
Crested wheatgrass	35	1	0.03	1.3
Western wheatgrass	35	1	0.03	1.3
Meadow bromegrass	35	1	0.03	1.3
Russian wildrye	30	1	0.03	1.3
Altai wildrye	30	1	0.03	1.3

[z] WA is the radiation-use efficiency. RBMD defines the shape of the curve for decrease in radiation-use efficiency after anthesis. HI is the harvest index, i.e., the dry matter of the economic or seed yield divided by the total above-ground dry matter at maturity. RDMX is the maximum rooting depth.

PARAMETERS FOR COLD-TEMPERATURE INJURY. Two parameters define the curve for how leaf area is lost with cold-temperature stress: FRS1 and FRS2 (Table 2). Using corn as an example, 15% of current leaf area is lost for each day with minimum temperature at −5°C, and 95% is lost for each day at −15°c. For spring wheat these values are 0.1% at −5°C and 1% at −15°C.

GROWING-DEGREE DAYS FROM PLANTING TO MATURITY. EPIC can either use input PHU values or calculate them with the temperature data if the days to maturity is input. Values of PHU chosen for the canola species were based on the growth-season durations for spring wheat and spring barley (Table 2). Spring wheat and Argentine-type canola require a similar number of days to mature. Spring barley maturity is similar to that of Polish-type canola (Alberta Agriculture 1985). Average time to reach maturity in Saskatchewan is 97–103 d for spring wheat and 89–94 d for spring barley. Requirements for canola are 95 d for Argentine and 85 d for Polish. At Lethbridge, Alberta (Major and Hamman 1981), spring wheat required 104–111 days to reach maturity, while spring barley required 97–104 d.

Physical Descriptions of Plant Growth

BIOMASS GROWTH. WA is the dry biomass, including roots, produced per unit of intercepted photosynthetically active radiation under non-stress conditions (Table 3). Values for all plant species except canola are from Williams et al. (1989). The WA value of 34 kg ha^{-1} MJ^{-1} m^2 for canola is derived from results of M. Morrison (unpubl. observation for 1984) at Winnipeg and Smith, A. M. and Major, D. J. (pers. commun.) at Lethbridge. At Temple, Texas (J.R. Kiniry, unpubl. observation), canola WA prior to anthesis (March–April 1993) was 35 kg ha^{-1} MJ^{-1} m^2 for aboveground total biomass and 40 kg ha^{-1} MJ^{-1} m^2 for the total including roots. During anthesis, the proportion of the total biomass that was roots at Temple was 6% on 23 March, 10% on 12 April, and 12% on 23 April. Canola grown in Japan (Inanaga and Kumra 1974) had 13% of the total biomass in roots in anthesis and 8% at maturity. Canola in Britain (Allen and Morgan 1972) had 10–11% of the total in roots from 9 to 16 wk after sowing. Thus, the WA value for canola of 31 kg ha^{-1} MJ^{-1} m^2 for shoot data supplied by Morrison is 34 kg ha^{-1} MJ m^2 if 10% for roots is considered. In Britain (Mendham et al. 1981), canola WA for above-ground biomass was 27 kg ha^{-1} MJ^{-1} m^2, assuming 45% of total solar radiation is photosynthetically active radiation (Meek et al. 1984).

Parameter RBMD is the rate of decline in WA after LAI starts to decrease and is comparable to the LAI decline rate factor (RLAD). For canola, using data from Inanaga and Kumra (1974), net photosynthesis divided by the sum of LAI and pod area index decreases nonlinearly. WA should change similarly over time, and thus RBMD is 0.3 for canola. For all other species, RBMD is 1.0 to allow a linear decrease.

HARVEST INDEX. Because of their prominence in the study region, wheat, barley, and canola were the main crops investigated for harvest index (dry seed weight divided by total above-ground dry weight) for this project (Table 3). Values of HI for other crops modeled in EPIC are described elsewhere (Williams et al. 1989). The HI for spring wheat is from Major and Hamman (1981), Major et al. (1992), and Nass (1987). The HI for winter wheat is from Singh and Stoskopf (1971). The minimum HI for wheat under stress is 0.19, based on results with nutrient stress at Winnipeg (Racz et al. 1965).

Spring barley HI is greater than HI for wheat. Values of HI for spring barley at Lethbridge, Alberta, varied from 0.45 to 0.59 (Major and Hamman 1981). In Ontario, spring barley HI was 0.52 (Singh and Stoskopf 1971), while for two barley varieties in Britain HI was 0.47 when the soil was heated and 0.45–0.50 when the soil was not heated (Hetherington and Stewart 1988).

Canola HI is greater for Argentine type than for Polish type (Table 3). Values for HI with Argentine were 0.31 in Australia (Hodgson 1979), 0.24–0.31 at Edmonton, Alberta (Degenhard and Kondra 1984), and 0.26–0.31 at Melfort, Saskatchewan (Nuttall and Button 1990). The mean HI was 0.29 for a study with several European cultivars of winter Argentine canola in Germany (Hühn et al. 1991). Values for Polish were 0.23–0.28 in Alberta (Krogman and Hobbs 1975) and 0.26–0.29 in India (Sinha et al. 1982).

Canola HI drops to as low as 0.17 with severe stress near flowering (WSYF = 0.17). This value is supported by the following results: those in Australia (Hodgson 1979), with Argentine, where the lowest HI values were 0.19 and 0.15; those in Britain (Scott et al. 1973), where the most severe treatment with Argentine had HI equal to 0.17; and those in Britain (Mendham et al. 1981), with Argentine, where the mean HI of the lowest four treatments was 0.17.

POTENTIAL ROOTING DEPTH. Potential rooting depth is 0.9 m for canola, 2.0 m for corn and wheatgrass species, and 1.3 m for all other species (Table 3). Entz et al. (1992) found the RDMX of spring and winter cereals varied from 1.1 to 1.3 m in Saskatchewan.

Nitrogen and Phosphorus

Nutrient concentrations (Tables 4 and 5) are mainly from Morrison (1956), although many improvements or additions were made using more recent results from this region. Concentrations consist of whole-plant values near seedling emergence, near the middle of the season, and at maturity. Concentration in the dry yield is also required by EPIC.

Nitrogen and phosphorus in the whole plant and in the grain at maturity of wheat, barley, and corn are reported values of the Saskatchewan Agricultural Services Co-ordinating Committee (1987). In mature wildrye plants, phosphorus concentration is from Smika et al. (1960), and nitrogen concentration is from Power (1986). Nitrogen and phosphorus concentrations in wheatgrass species at maturity are those of Smika et al. (1960), Halvorson and White (1981), Power 1983, 1986), and White and Wight (1981). Nitrogen and phosphorus in meadow bromegrass and smooth bromegrass are from Nuttall (1980), Usherwood (1978), Eck et al. (1981), and Power (1986).

Table 4. Input nitrogen fractions for dry biomass at different growth stages and for seed yield

Crop	Fraction of N at: Seedling emergence	Mid-season	Maturity	Fraction of N in dry yield
Spring and winter wheat	0.0663	0.0255	0.0148	0.025
Spring barley	0.0590	0.0226	0.0131	0.021
Canola	0.0440	0.0164	0.0128	0.038
Corn	0.0470	0.0177	0.0138	0.014
Wildrye	0.0226	0.0180	0.0140	0.023
Wheatgrasses and warm season grasses	0.0300	0.0200	0.0120	0.0500
Bromegrasses	0.0400	0.0240	0.0160	0.0234

Table 5. Input phosphorus fractions in dry biomass at different growth stages and for seed yield

Crop	Fraction of P: Seedling emergence	Mid-season	Maturity	Fraction of P in dry yield
Spring and winter wheat	0.0053	0.0020	0.0012	0.0022
Spring barley	0.0057	0.0022	0.0013	0.0017
Canola	0.0074	0.0037	0.0023	0.0079
Corn	0.0048	0.0018	0.0014	0.0016
Warm season grasses	0.0049	0.0019	0.0011	0.0033
Wildrye	0.0040	0.0040	0.0024	0.0037
Wheatgrasses and summer pasture	0.0020	0.0015	0.0013	0.0040
Bromegrasses	0.0028	0.0017	0.0011	0.0033

FIELD DATA

The first group of data sets for evaluating model performance are from six sources. The soils varied widely across locations (Table 6). The first source is 19 years of yield data at the farm of Mr. Les Auer, near Billings, Montana. The data consist of dryland winter and spring wheat yields grown on two soil types in crop–fallow rotations. Applied N was assumed to be 80 kg N ha^{-1} yr^{-1}. Daily temperature and rainfall data are from Billings, with solar-radiation data simulated with the techniques of WGEN (Richardson and Wright 1984). Monthly means for 20 yr at Billings are used.

The second data set consists of grass-forage yield results from a study conducted by White and Wight (1981) on a fine

Table 6. Input parameters for soils used in model demonstration

Location	Soil classification/ soil name	Soil depth (m)	PAW[z] fraction	Curve[y] No.	Soil texture[x]	Organic carbon[w]
Lethbridge, AB	Dark Brown Chernozem	1.22	0.144	91	38% sand 36% silt	5.00
Edmonton, AB de St. Remy (1991) data	Eluviated Black Chernozem	1.65	0.141	91	26% sand 34% silt	2.50
Edmonton, AB Degenhart and Kondra (1984) data	Black Chernozem	1.65	0.135	91	48% sand 26% silt	4.99
Peace River, AB	Dark Gray Luvisol	1.65	0.141	91	47% sand 26% silt	2.20
Pincher Creek, AB	Thin Black Chernozem	1.00	0.105	91	1% sand 24% silt	1.90
Winnipeg, MB (Aboretum site)	Orthic Dark Brown Chernozem	1.00	0.105	81	2% sand 28% silt	1.90
Winnipeg, MB (Point site)	Riverdale loamy sand	1.52	0.084	81	84% sand 9% silt	0.76
Swift Current, SK	Wood Mountain loam	1.10	0.130	91	38% sand 36% silt	2.10
Billings, MT	Vanada silty clay	0.94	0.121	85	27% sand 30% silt	0.23
Billings, MT	Fort Collins clay loam	0.38	0.118	85	23% sand 29% silt	1.16
Sidney, MT	Williams loam	1.93	0.110	85	38% sand 36% silt	1.26
Mandan, ND	Cheyenne fine sandy loam	1.02	0.158	85	42% sand 42% silt	0.50

[z] Plant available water in the profile on a volumetric basis.
[y] Runoff curve number.
[x] Soil texture in the first 1.0 m of soil.
[w] Organic carbon in the plow zone (the top two layers of soil).

loamy mixed Typic Argiboroll at the Northern Plains Soil and Water Research Center near Sidney, Montana. Species include crested wheatgrass, Altai wildrye, Russian wildrye, and meadow bromegrass for 1975 and 1976. Simulated harvests occur at maximum reported dry matter: on 20 July for crested wheatgrass, 6 July for meadow bromegrass, and 29 June for wildrye. EPIC's accumulated seasonal plant biomass values, with no applied nutrients, are compared with the published values. Additional data for this location involve western wheatgrass for 1969 and 1970 (Wight and Black 1972). Actual temperatures and precipitation are used for 1969 and 1970. Model simulations are for the highest fertility treatment, where western wheatgrass was the dominant species.

The third data set is from a research project with crested wheatgrass, Russian wildrye, and smooth bromegrass at Mandan, North Dakota, on a Cheyenne fine sandy loam for 7 yr (Smika et al. 1960). We applied 67 kg N ha^{-1} yr^{-1} with EPIC. Actual weather data are unavailable, so we simulated weather for 15 yr with WGEN. The average yield for the last 13 yr, allowing 2 yr for establishment, is compared with reported yields.

A fourth data set (Major et al. 1991) involves irrigated corn hybrids at the Agricultural Canada Research Station in Lethbridge, Alberta, for a 3 yr period on a Typic Haploboroll (Dark Brown Chernozemic). We applied 170 kg N ha^{-1} yr^{-1} for EPIC. Data from growing dryland wheat and barley for 2 yr (Major and Hamman 1981), crops also studied at the Agriculture and Agri-Food Canada Research Station at Lethbridge, provided a comparison of growth dynamics of these two cereals. A weather station located within 1 km of the test site was the source of monthly rain totals for May, June, and July. We applied 58 kg N ha^{-1} yr^{-1} for EPIC.

The fifth data set, acquired by Campbell et al. (1983), compares different rotations involving wheat and N and P fertility over a period of 12 yr at Swift Current, Saskatchewan. We used measured temperatures and rainfall from the site. The nearest available solar radiation data, from Lethbridge, Alberta, were used. For the simulations, we applied 34 kg N ha^{-1} yr^{-1}. The sixth database involves crested wheatgrass at Pincher Creek, Alberta (Lutwick and Smith 1977), on a Standoff loam, Thin Black Chernozemic. Crested wheatgrass was fertilized at four levels of N. We generated weather data, using WGEN, for the Pincher Creek weather station, substituting the rainfall amounts reported in the paper for the 3-yr. For the simulations, we applied 180 kg N ha^{-1} yr^{-1}.

The second group of data sets, all five for canola, are from four Canadian locations. The first two data sets are from Winnipeg, Manitoba. In the first, Van Deynze et al. (1992) reported results with Argentine type canola. Using actual weather data for 1986 and 1987, we compared mean results

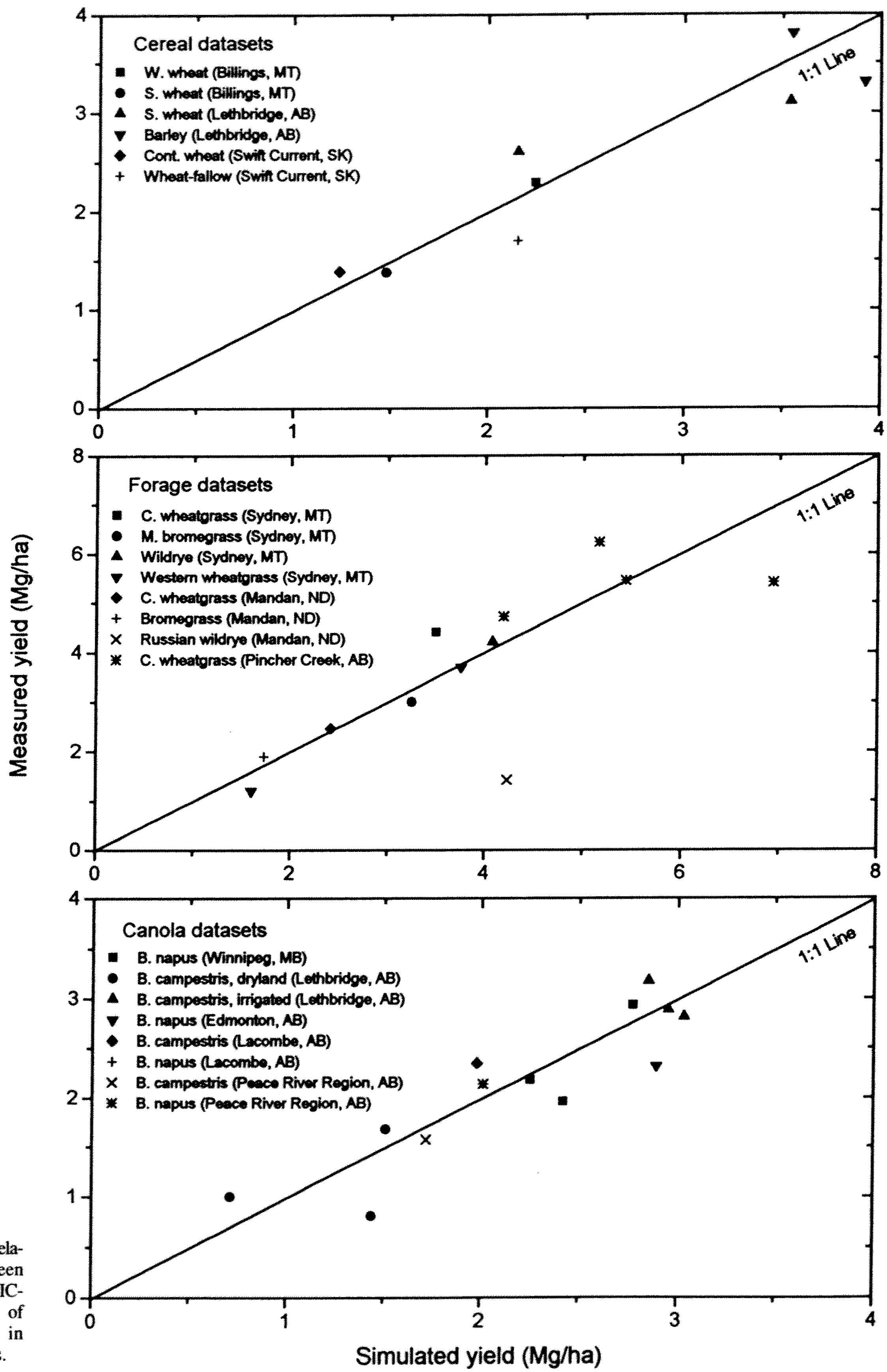

Fig. 1. Overall relationships between measured and EPIC-simulated yield of plant species in northern latitudes.

for these 2 yr with the mean results reported for 1986, 1987, and 1990. Parameters are for Westar variety because it was one of the two "conventional" hybrids in the study. However, we reduced the potential LAI (DMLA) to two thirds of those of Morrison et al. (1990). We used parameters for the Drumheller soil series provided by C. Izaurralde, with 70–76% clay and 1.0 m depth. For the second Winnipeg data set (Morrison et al. 1990), we measured weather data for 1984–1986 and irrigation data. The soil was the same as for the Van Deynze data, and the variety was Westar. Comparisons between simulated yields and measured yields were made at the recommended seeding rate of 6.0 kg ha^{-1}. For the EPIC runs, we applied 18 kg N ha^{-1} yr^{-1} at the Point site and none at the Arboretum site.

At Lethbridge, Krogman and Hobbs (1975) measured yield for 3 yr for Polish type. Actual weather data for the site and years were available, and we simulated the 56 kg N ha^{-1} and 56 kg P ha^{-1} treatment each year. Input HI was 0.28 for Polish, and there were 910 GDD to maturity, a 1 May planting, and a 1 August harvest.

For Edmonton, Alberta, weather data from the Edmonton Namao station were used to generate 10 yr of weather data, with planting occurring 17 May each year for the Degenhart and Kondra (1984) simulation. For the de St. Remy (1991) simulation, we planted 23 May each year for 10 yr, applying no N, generating weather from means for the Lacombe site. We applied no N for the Edmonton simulations.

For the Peace River region of Alberta (Woods 1992), we generated 20 yr of weather with WGEN, using monthly means from the Peace River A station. Because of the extremely northern latitude, GDD to maturity (PHU) was 800 for both species. For the simulations, we applied 100 kg N ha^{-1}.

RESULTS

The results demonstrate that, with the plant parameters described above, EPIC produced satisfactory simulations (Fig. 1). Values were generally close to the 1:1 line, with only a few simulations having large differences from the measured yields. Because the corn results were whole-plant dry matter, they were not included in Fig. 1.

Cereal and Forage Data Sets

BILLINGS, MONTANA. Winter wheat had mean simulated yields of 2.30 ± 0.72 Mg ha^{-1} (X ± SD) and 2.18 ± 0.59 Mg ha^{-1} on the two soils, for an overall mean of 2.24 ± 0.63 Mg ha^{-1}. This was 98% of the long-term mean harvested yield of 2.29 Mg ha^{-1}. Spring wheat had mean simulated yields of 1.88 ± 1.06 and 1.09 ± 0.71 Mg ha^{-1} on the two soils, for a mean overall mean of 1.48 ± 0.86 Mg ha^{-1}. This is 107% of the long-term mean harvested yield of 1.38 Mg ha^{-1}.

SIDNEY, MONTANA. We compared EPIC's output in 1976 only, because White and Wight (1981) wrote that "1975 was the first year after seeding [and thus] seasonal growth among species can be best compared from the 1976 yield curves." Simulated yield for crested wheatgrass was 3.5 Mg ha^{-1}, 80% of the measured value of 4.4 Mg ha^{-1}. Simulated yield for meadow bromegrass was 3.25 Mg ha^{-1}, 108% of the measured value of 3.0 Mg ha^{-1}. Finally, simulated yield for Altai and Russian wildrye was 4.08 Mg ha^{-1}, 97% of the measured value of 4.2 Mg ha^{-1}.

Measured yields of western wheatgrass were 1.60 and 3.76 Mg ha^{-1} in the 2 yr, for a mean of 2.68 Mg ha^{-1}. Simulated yields were 1.21 and 3.70 Mg ha^{-1}, for an average yield of 2.46 Mg ha^{-1}, 92% of the measured mean.

MANDAN, NORTH DAKOTA. Smika et al. (1960) reported only mean yields for the 7 yr. As we found for the Sidney, Montana, data, EPIC best simulates wildrye forage production after establishment, the third year after seeding. Simulated yield of crested wheatgrass was 2.42 ± 0.90 Mg ha^{-1}, 98% of the measured value of 2.47 Mg ha^{-1}. Simulated yield for bromegrass was 1.73 ± 0.60 Mg ha^{-1}, 91% of the measured value of 1.90 Mg ha^{-1}. Simulated yield for Russian wildrye was 4.19 ± 0.86 Mg ha^{-1}, 293% of the mean measured value of 1.43 Mg ha^{-1}. Russian wildrye was "further advanced [beyond the bloom stage] at harvest than the other two grasses." Thus it may have lost some of its forage biomass by harvest.

LETHBRIDGE, ALBERTA. The corn data of Major et al. (1991) had a measured whole-plant dry matter yield of 14.1 ± 1.5 Mg ha^{-1} (mean ± SD). EPIC's mean simulated value, with 10 yr of generated weather, is 16.1 ± 0.7 Mg ha^{-1}, 114% of the measured value.

The simulated yields of dryland spring wheat and spring barley were similar to the measured yields of Major and Hamman (1981) (Table 7). On average, EPIC's simulated yields were within 5% of measured values.

Table 7. Simulated and measured dryland spring wheat and spring barley yields at Lethbridge, AB (Major and Hamman 1981)

		Yield (Mg ha^{-1})	
		Measured	Simulated
Wheat	1976	3.1	3.54
	1977	2.6	2.15
	Mean	2.85	2.85 (100% of measured)
Barley	1976	3.3	3.93
	1977	3.8	3.55
	Mean	3.55	3.74 (105% of measured)

SWIFT CURRENT, SASKATCHEWAN. Simulated yield of continuous wheat had a mean of 1.42 ± 0.49 Mg ha^{-1}, 103% of the measured value of 1.39 ± 0.37 Mg ha^{-1} (Fig. 2). For the first 6 yr, the r^2 for the linear relationship between simulated and measured yields was 0.29. There was no significant relationship between simulated and measured yields in the last 6 yr.

Simulated wheat yield, with fallow on alternate years, was 1.55 ± 0.49 Mg ha^{-1}, 86% of the measured yield of 1.81 ± 0.48 Mg ha^{-1} (Fig. 3). The r^2 for the linear relationship between simulated and measured yields was 0.19 for all 12 yr of results.

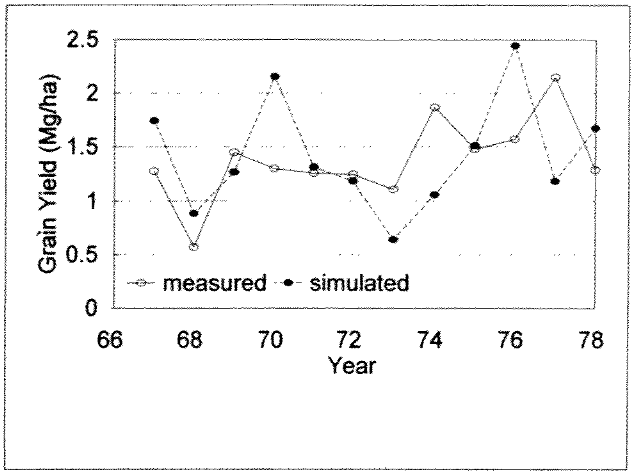

Fig. 2. With the continuous-wheat data at Swift Current, SK (Campbell et al. 1983), comparisons between simulated and measured values.

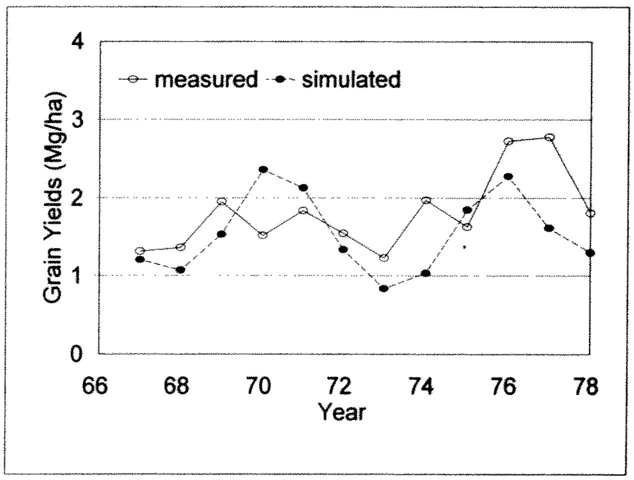

Fig. 3. With the alternate-fallow-year wheat data at Swift Current, SK (Campbell et al. 1983), comparisons between simulated and measured values.

PINCHER CREEK IN SOUTHERN ALBERTA. The EPIC model reasonably simulated the mean response of crested wheatgrass yields to fertilizer but failed to account for year-to-year variability (Table 8). The mean yield for the treatment fertilized every year was 100% of measured yield. The mean yield for the treatment fertilized the first year showed a reduction, but not as great a reduction as that for the measured yields.

Canola Data Sets

WINNIPEG, MANITOBA. In the Van Deynze et al. (1992) study, only the mean yield was reported for the 3 yr, combined for Westar and Regent varieties and combined for the Arboretum and Point locations. The mean simulated yield was 2.51 Mg ha^{-1} for 1986 and 2.33 Mg ha^{-1} for 1987, for a mean of 2.42 Mg ha^{-1}. This was 23% greater than the mean measured yield of 1.96 Mg ha^{-1} for 1986, 1987, and 1990.

The simulated yield for the Morrison et al. (1990) data for 1985 and 1986 was 2.77 Mg ha^{-1} (2.82 in 1985 and 2.71 in 1986), 94% of the 2.93 Mg ha^{-1} yield at Point (3.04 in 1985 and 2.82 in 1986). The predicted yield at Arboretum in the one measured year (1986) was 2.25 Mg ha^{-1}, 103% of the measured yield value of 2.18 Mg ha^{-1}.

LETHBRIDGE, ALBERTA. The simulated yields were reasonable for the irrigated and dryland treatments (Table 9). Simulated yields under irrigation were 2–10% different from measured yields. The mean simulated irrigated yield was 100% of the measured value. Dryland simulated yields were much greater than measured yields in 2 of the 3 yr.

EDMONTON, ALBERTA. Degenhart and Kondra (1984) reported that the mean yield for 2 yr was 2.32 Mg ha^{-1} for Argentine type, while our simulated mean for 10 yr was 2.89 ± 0.78 Mg ha^{-1}, 125% of the measured yield. For the mean yield for 2 yr, de St. Remy (1991) reported 2.35 Mg ha^{-1} for Polish type (2.32 and 2.37 Mg ha^{-1}) and 2.14 Mg ha^{-1} for Argentine (2.96 and 1.31 Mg ha^{-1}). Our simulated mean values were 1.98 Mg ha^{-1} for Polish (84% of measured) and 2.22 Mg ha^{-1} for Argentine (104% of measured).

THE PEACE RIVER REGION, ALBERTA. Woods (1992) reported 2.14 Mg ha^{-1} for Argentine type and 1.58 Mg ha^{-1} for Polish type. Mean and standard deviation of simulated yields for Argentine type were 2.01 ± 0.83 (94 ± 39% of measured). Mean and standard deviation of simulated yields for Polish type were 1.72 ± 0.59 Mg ha^{-1} (109 ± 37% of measured).

Table 8. Simulated and measured crested wheatgrass yields (Lutwick and Smith 1977) at Pincher Creek, AB

	Yield (Mg ha^{-1})	
	Measured	Simulated
	When fertilized first year only	
Year 1	4.72	4.19 (89%)
Year 2	4.09	5.16 (126%)
Year 3	1.98	3.02 (153%)
Mean	3.60	4.12 (115% of measured)
	When fertilized every year	
Year 1	4.72	4.19 (89%)
Year 2	6.23	5.16 (83%)
Year 3	5.40	6.94 (129%)
Mean	5.45	5.43 (100% of measured)

Table 9. Simulated (sim.) and measured (meas.) canola yields for Lethbridge, AB (Krogman and Hobbs 1975)

	Yield (Mg ha^{-1})			
	Dryland sim.	Dryland meas.	Irrigation sim.	Irrigation meas.
Year				
1971	1.44	0.81	2.95	2.88
1972	1.51	1.68	2.85	3.17
1973	0.71	1.00	3.03	2.81
Mean	1.22	1.16	2.94	2.95
	(105% of measured)		(100% of measured)	
SD	0.44	0.46	0.09	0.19

DISCUSSION

The usefulness of any agricultural simulation model depends on adequate accuracy in simulating both long-term mean yields and short-term year-to-year trends. Model validity for long-term means is important for issues such as soil erosion, agricultural sustainability, climate change, and groundwater quality. Model validity for year-to-year trends is needed for issues such as annual economic forecasts and optimization of applied nutrients, of irrigation, and of crop-maturity type.

The EPIC model, with its components for hydrology, nutrient balances, soil erosion, and crop development, has been reported to be most adequate for simulating long-term average crop yields in Canada (Moulin and Beckie 1993; Touré et al. 1995). Results of the present study show that EPIC can give reasonable mean-yield simulations for the major crops and forages in the northern Great Plains. However, further work is needed, with intense investigation of the model's inability to adequately simulate yield in some low-yielding years and the model's inability to simulate year-to-year variability in yield. Overestimation of the amount of plant-available water at field capacity can cause a model to overestimate yield in dry years. The robustness of the harvest-index approach in EPIC, even with its ability to reduce harvest index when there is stress near flowering, needs to be examined. Field measurements of maximum depth of water extraction and of harvest index in severe drought treatments, using appropriate cultivars in the region, would be helpful.

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