THE UNIVERSITY OF MANITOBA

A STUDY OF THE POTENTIAL OF HYBRID RYE (*Secale cereale* L.) PRODUCED BY CROSSES BETWEEN INBRED LINES.

by

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ABSTRACT

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Thirteen rye hybrids were produced by making thirteen crosses between eleven different, unselected inbred lines which had been inbred for at least four generations. Two experiments were performed using this material. In the first, the hybrids and inbreds together with some outbreeding rye varieties and some wheat and triticale lines were grown in the field . During the growing season a total of eleven different characters of the material were evaluated. In the second experiment some hybrids and inbreds were grown in a controlled enviroment cabinet and early growth characteristics of the lines were evaluated up to 38 days after seeding.

Hybrids initially had smaller seed than the inbreds. This was attributed to the crossing technique used in producing the hybrid seed. However, this factor did not affect the early growth of the hybrids as in the field, emergence was significantly better than that of the inbreds. Hybrids were also superior to the inbreds in their early growth as measured in the controlled enviroment cabinet. Hybrids were significantly different from the inbreds in all other characters. They headed earlier, had more tillers per plant, were taller, and had more florets per head. The hybrids also had significantly higher cross and self-fertility than the inbreds under field conditions, yielded significantly more and had a significantly higher one hundred kernel weight than the inbreds.

When compared to the control variety Gazelle the hybrids as a group were similar in many respects although individual lines differed from Gazelle. The hybrids were not significantly different from Gazelle in either emergence, days to heading, head size or the level of fertility. As expected the outbred varieties were very self-sterile, whereas the hybrids had high self-fertility. The hybrids also had significantly more tillers per plant than Gazelle and were significantly taller. Although the hybrids as a group had significantly lower yield than Gazelle and smaller one hundred kernel weight, certain hybrids were superior to Gazelle.

It was concluded that with suitable selection of inbred lines, hybrids could be obtained which were superior to the current outbred varieties. Further tests would be required to determine the full potential of hybrid rye and its economic feasibility.

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1. INTRODUCTION

In Western Canada in 1974 rye occupied only 340,000 hectares, just 1.8% of the 18.9 million hectares sown to the four major small-grain cereals (wheat, barley, oats and rye). Traditionally rye has never been held in high esteem as either a bread grain, because of the heavy dark loaf it produces (Horsley 1969), or as an animal feed, because of the low palatability and growth inhibiting factors associated with high levels of rye in a ration (F.A.O. 1965). Due to this reputation world demand for rye has decreased whereas demand for the other cereals continues to increase. As a result world prices for rye have been lower and profits to the farmer less than for other small-grains (F.A.O. 1965). Nevertheless, rye has advantages over the other cereals with respect to winter-hardiness and its ability to grow on sandy or infertile soils which cannot sustain the other cereals (Reeves 1971). With adequate fertilization, rye yields equal to wheat are attainable and its quality with respect to protein and amino-acid balance is generally recognized as being as good as or better than that of wheat (Canada Grains Council 1974).

There is now a growing awareness in Western Canada of the potential of rye as "the preferred grain crop for extensive areas, especially for rotation purposes with other cereals" (Canada Grains Council 1970). If problems of palatability and growth inhibition can be determined and overcome an increase in demand for rye as an animal feed might be expected. It would seem desirable to have some improved, adapted, high-yielding rye varieties available. In the past a minimum of effort has been afforded rye by Canadian plant-breeders, many of the varieties being based on selections from introduced varieties. There is now interest in attempting to improve rye using some of the established methods of breeding cross-pollinated crops. One possible breeding technique would be to utilize heterosis in rye and produce hybrid varieties. Virtually 100% of the corn now grown in North America is hybrid corn produced by controlled crossing of inbred-lines. Rye, like corn, is a naturally outbreeding plant and similar inbred lines have been produced and maintained. With the recent discovery and release of a source of cytoplasmic male-sterility in rye (Geiger and Schnell 1970), the mechanics of producing an F_1 rye hybrid are relatively simple and the prospect of a hybrid rye variety seems much closer. This study was undertaken in an attempt to ascertain the feasibility of hybrid rye production by obtaining some measure of the level of heterosis expressed in F_1 rye hybrids produced by crossing inbred lines.

2. LITERATURE REVIEW

2.1 The Origin and Domestication of Rye

Cultivated rye, *Secale cereale* L. is classified as belonging to the tribe *Triticeae* of the family *Gramineae*. The genus *Secale* contains only four to twelve species (depending on the criteria used) most of which have been suggested as the immediate ancestor of cultivated rye by various authors (Stutz 1972). Stutz has recently proposed that cultivated rye originated from weedy products derived from the introgression of *S. montanum* Guss. into *S. vavilovii* Grossh., *S. vavilovii* itself having been derived from *S. silvestre* Host. *S. silvestre* in turn was thought to have been derived from *S. montanum* or a common ancestor. As *S. vavilvoii* evolved from *S. montanum* via *S. silvestre* an evolutionary series of stepwise translocations occurred which have recently been identified by van Heemert and Sybenga (1972).

The early forms of cultivated rye are thought to have evolved after the period 7,000 B.C. that is now estimated for the origin of wheat and barley (Horsley 1969). The first weedy forms of rye are believed to have evolved in central Asia about 6,000 years ago (Helbaek 1971). Unlike wheat and barley which were domesticated in the immediate area of their centre of origin, and then spread as a crop, Helbaek has suggested that rye was introduced into Europe via the Balkan peninsula as a weed of other cereals. He further proposes that nomads were responsible for the original introduction, and rye then became distributed throughout Europe and into Russia by armies and other travelling people. Its dissemination as a weed was originally aided by the presence of rough awns and a fragile rachis (Helbaek 1971). Domestication of rye is thought to have taken place at several independent locations (Khush 1963). As it was carried as a weed into higher altitudes and more Northerly latitudes its competitive ability relative to wheat and barley increased, and eventually rye became the dominant component of the crop (Helbaek 1971). As domestication proceeded unconscious selection favoured a stiff, non-shattering rachis, and winnowing favoured a larger grain (Khush 1963). As a result, rye became the primary bread-grain of much of Eastern Europe, Russia, Germany, the low countries and Scandinavia until the 17th century and was brought across to the New World as an important staple of the Founding Fathers (Horsley 1969).

2.2 The History of World Rye Production and Consumption

Once the most common bread grain in much of Europe and Russia, the importance of rye as a major cereal has declined steadily since the seventeenth century (Horsley 1969). By 1918, world wheat production had increased to a level double that of rye. In the last half-century production of wheat has more than tripled, whereas rye production reached a peak in the pre-war period 1934-39 and has since declined to the level of the early twentieth century. However, in recent years production seems to have stabilized at around 30 million metric tons (Figure 1) less than 10% of the 1974 world wheat production. In the last forty years decreases in production of rye have been paralleled by similar decreases in the acreage grown in major producing areas (Russia, Eastern Europe, Western Europe and North America) (Figure 2) but these have been partly offset by consistent increases in yield obtained through the use of better varieties and improved cultural practices (Figure 3).

Changes in food preference have been largely responsible for the decline in popularity of rye as a bread-grain, especially in Teutonic and Slavic nations where rye has been the traditional bread (Horsley 1969). Also, increased affluence in industrial Europe allowed the switch to the more expensive wheat bread as people clung to the ancient belief that the dark, compact rye bread was an inferior product (Horsley 1969). As incomes increased further, and wheat bread became less expensive because of new wheat varieties and improved technology, wheat was able to oust rye as the dominant food grain (Schaben 1948). This trend seems irreversible and has continued up to the present day in both Russia and Eastern Europe. Poland is now the only country where rye production is greater than wheat but if trends continue, by 1976 wheat

FIGURE I. PRODUCTION OF RYE IN THE MAJOR PRODUCING AREAS OVER THE PERIOD 1924-1974. SOURCE: F.A.O. MONTHLY BULLETINS OF AGRICULTURAL ECONOMICS AND STATISTICS.

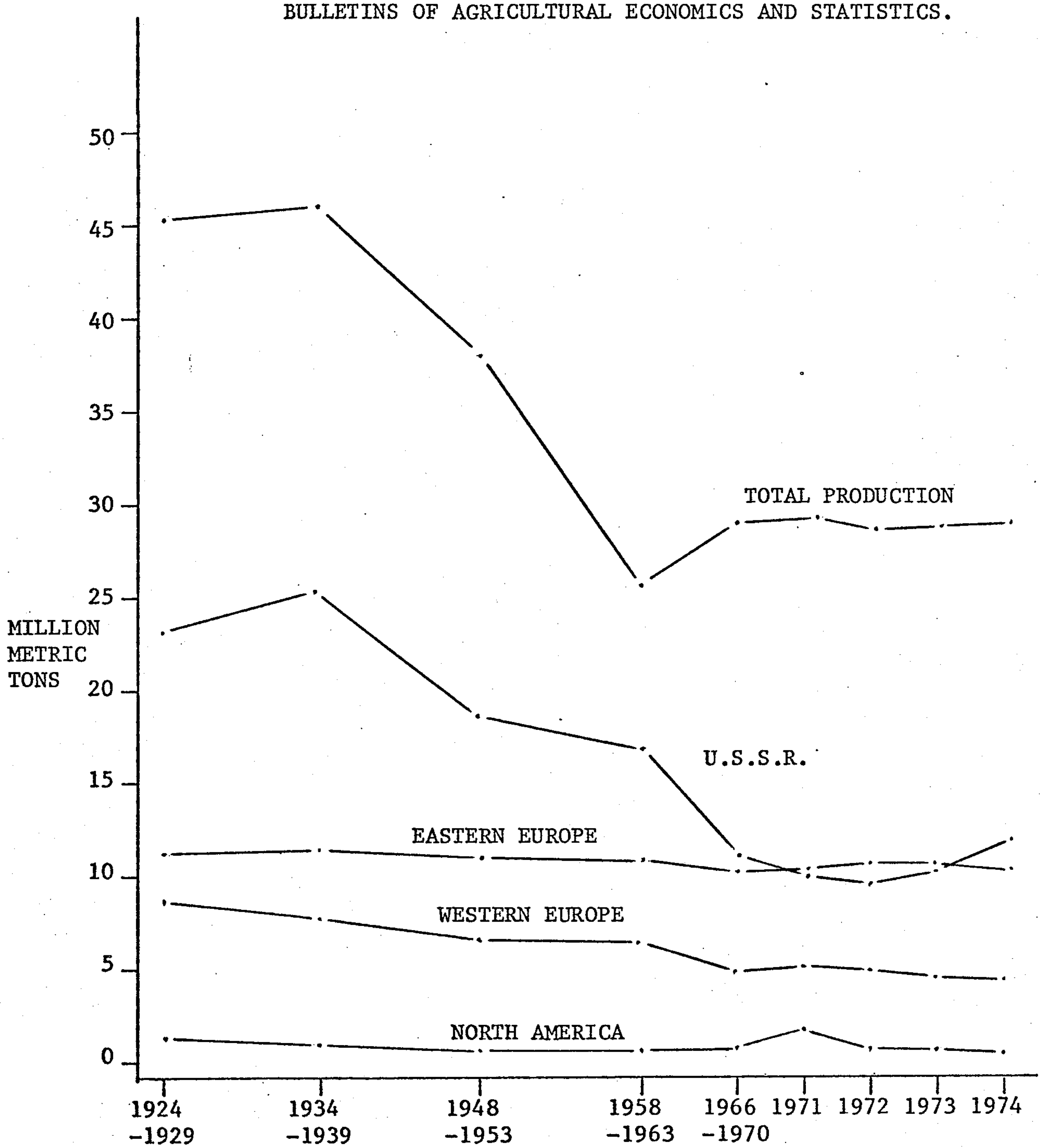


FIGURE 2. AREA OF RYE GROWN FOR GRAIN IN THE MAJOR PRODUCING AREAS OVER THE PERIOD 1924-1974.SOURCE:F.A.O. MONTHLY BULLETINS OF AGRICULTURAL ECONOMICS AND STATISTICS.

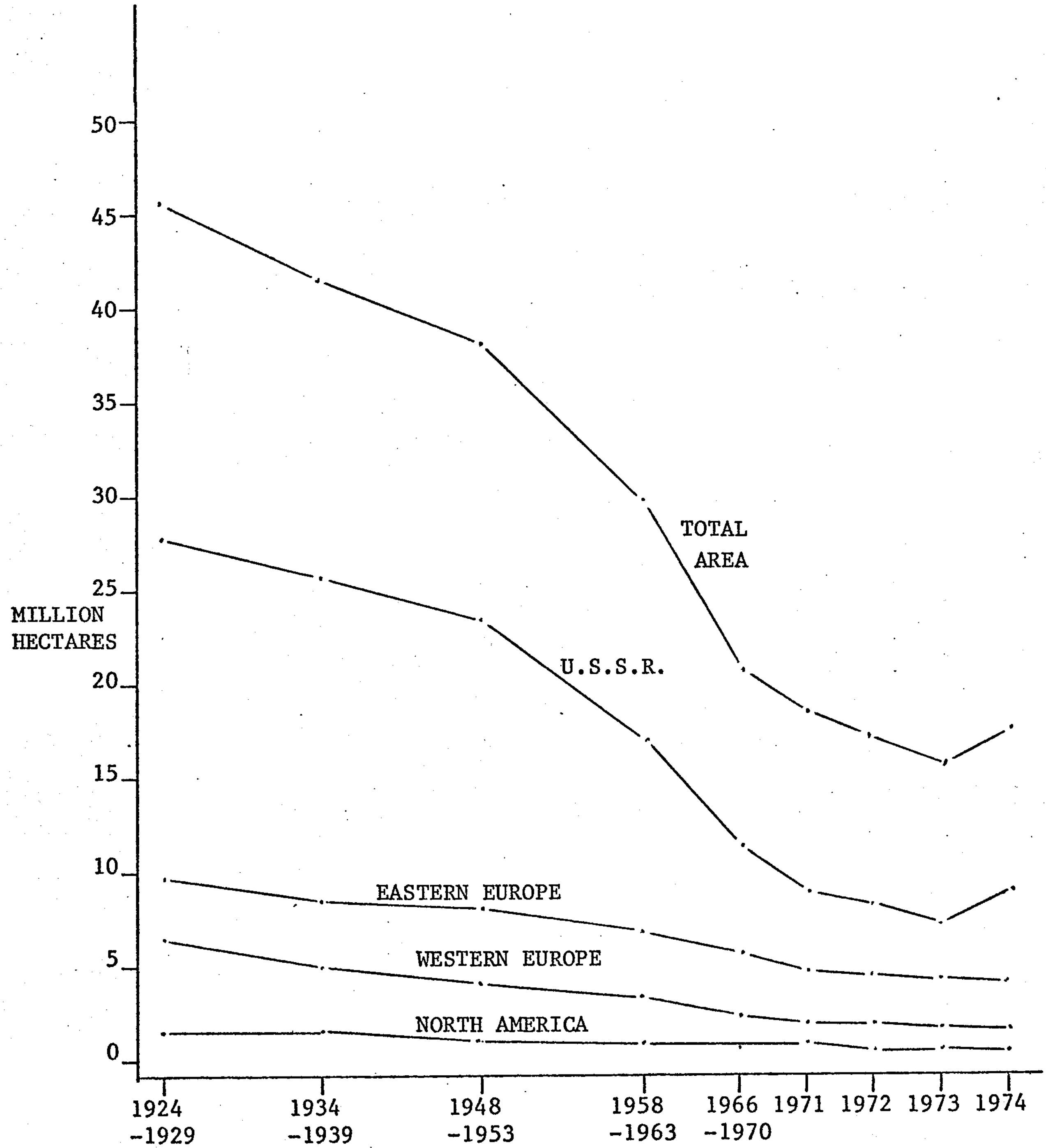
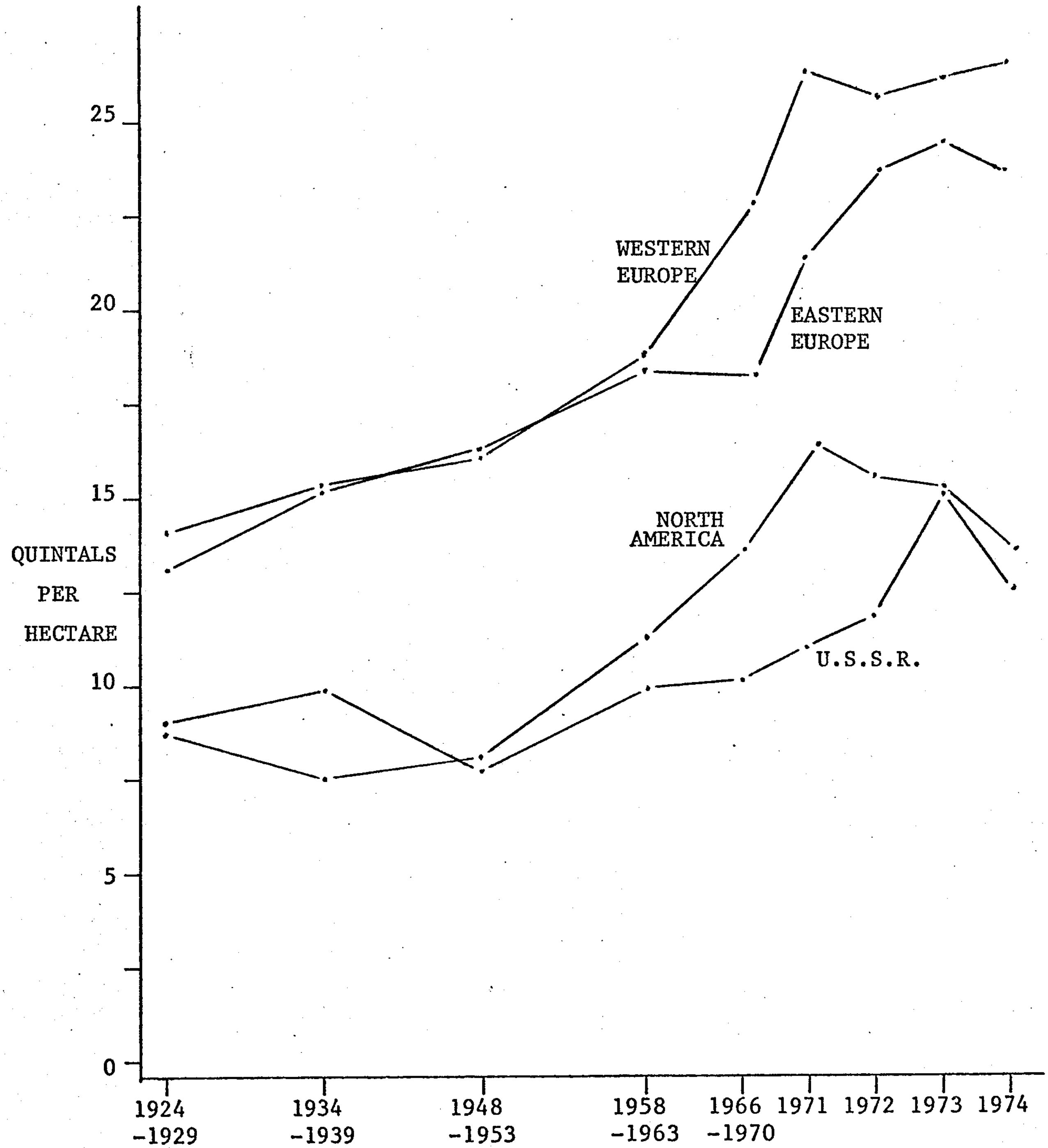


FIGURE 3. AVERAGE YIELDS OF RYE IN THE MAJOR PRODUCING AREAS OVER THE PERIOD 1924-1974. SOURCE:F.A.O. MONTHLY BULLETINS OF AGRICULTURAL ECONOMICS AND STATISTICS.



production will have increased above that of rye. However, it seems unlikely that traditional preferences for rye-bread in these areas will die out immediately (F.A.O. 1965).

In recent years the decline in consumption of rye in the form of bread has been partly offset by an increase in the use of rye as a feed grain. World figures for trends in rye consumption are not readily available, but figures obtained by the F.A.O. (Table 1) which exclude the centrally planned countries, the major areas of rye production and consumption, show that over the period 1955-1963 utilization of rye as a food declined from 4.0 to 3.5 million tons, whereas utilization as animal feed increased from 3.8 to 4.4 million tons. In Canada up to 1969 there had been only a slight increase in the use of rye for animal feed, 3,698 thousand bushels compared to 3,633 thousand in 1957. Over the same period human consumption of rye also increased from 429 to 450 thousand bushels (Carmichael and Norman 1970). In the U.S.A. human consumption of rye decreased from 5.2 million bushels in 1950 to 4.5 million bushels in 1960 and had returned to 1950 levels by 1970. Over the same period consumption as feed increased from 5.4 million bushels to 10.0 million bushels in 1960 and to 13.0 million bushels in 1970 (U.S.D.A. 1971). Because of this change in consumption patterns, rye, although like wheat a gluten containing grain (allowing it to be used in bread-making) is now regarded by bodies such as the F.A.O. as a feed or coarse grain rather than a bread grain.

TABLE 1. UTILIZATION OF RYE IN SELECTED COUNTRIES, AVERAGES 1955/56-1958/59 AND 1959/60-1962/63 (THOUSAND METRIC TONS).[1]

COUNTRY OR AREA	USE	
	FEED	FOOD
EUROPE AND SCANDINAVIA		
1955-1959	3,006	3,481
1959-1963	3,530	2,882
NORTH AMERICA		
1955-1959	321	131
1959-1963	307	127
ARGENTINA		
1955-1959	348	-
1959-1963	509	-
OTHERS		
1955-1959	110	406
1959-1963	70	481
TOTAL		
1955-1959	3,821	4,018
1959-1963	4,416	3,490

[1] (F.A.O. 1965).

2.3 Rye as an Animal Feed

It is unlikely that the recent rise in the feed uses of rye signifies a growing preference for rye in livestock feeding, but rather reflects its price advantage over other cereals as demand for rye has decreased (F.A.O. 1965). However, the future of rye as a crop in Canada will depend largely on an increase in its use as an animal feed. The previous limited use of rye in livestock feeding has been ascribed to the relatively low feed value of rye, and to the farmers traditional preferences for other grains (F.A.O. 1965), unwarranted prejudice against rye as a bread grain may have affected its popularity as a feed grain (Horsley 1969). Rye may also have been discredited as a feed because of its susceptibility to the disease ergot (*Claviceps purpurea* L.) which can be toxic to animals and may have contaminated early feed samples.

Knierem (1900) reported negative effects of feeding rye rather than barley after tests on a variety of animals. Crampton (1936) reviewed the literature on feed grains and concluded that of the five grains wheat, oats, barley, corn and rye; rye was inferior in its ability to sustain growth. Problems of feeding rye now seem to fall into three distinct areas; firstly, inclusion of rye in a diet has been found to affect palatability adversely resulting in decreased feed uptake. Secondly, high levels of rye in a diet have caused decreases in growth rates without a decrease in food uptake. And thirdly, rye has been found to induce various digestive disturbances in livestock, especially poultry. Problems of palatability, digestive disturbances and decreased growth rates have been associated with toxic substances present in the rye kernel and a number of experiments have been performed in an attempt to ascertain safe levels of rye in a diet and to identify these factors. The decreased growth rates of livestock fed diets containing high levels of rye have also been ascribed to the low nutritional value of the cereal *per se*.

2.3.A The presence of toxic substances in the rye kernel

Research to date has revealed three groups of substances present in the rye kernel which could potentially be responsible for the adverse effects of a rye diet:

i) Pentosans

ii) Trypsin inhibitors

iii) Alkyl resorcinols

i) Pentosans, or cereal gums, are polymers of araban and xylan sugar units, they have been shown to occur in all of the five major cereals although the pentosan concentration is higher in rye than in any of the other grains (Preece and MacKenzie 1952). Moran and McGinnis (1965) postulated that the high level of pentosans in rye might be indirectly responsible for the digestive disturbances associated with feeding the cereal to poultry (first noted by Halpin *et al.* 1936) by stimulating deleterious intestinal micro-flora. This hypothesis was based on the fact that when high levels of antibiotic were included in a rye-containing diet the adverse effects were overcome. Similar results were obtained by MacAuliffe and McGinnis (1971) and by Fernandez *et al.* (1974), however, the latter authors also reported improved protein efficiency ratios and higher weights of chicks when procaine penicillin was added to diets of corn, wheat and barley as well as rye. Moran and McGinnis (1965) proposed that the antibiotic treatment prevented the build up of an unfavourable intestinal micro-flora in poultry. This hypothesis seems acceptable with the knowledge that digestive disturbances seem to be limited to non-ruminant species, resulting characteristically in wet sticky faeces. Hungate (1966) pointed out that ruminant species maintain a large microbial flora in the rumen which is able to break down the pentosans before they reach the intestine. Consequently they cannot stimulate an adverse micro-flora and cause similar digestive disturbances. However, before this hypothesis can be accepted, further work seems to be required to confirm the results of tests with antibiotics on non-ruminant species other than poultry, and to attempt to identify the deleterious micro-flora and their antibiotic susceptibility (Haeberle 1974).

ii) Trypsin inhibitors, named because of their ability to bind the pancreatic enzyme trypsin into an inactive complex, are proteinaceous substances first isolated from the endosperm of rye by Polanowski (1967). Minja (1970) studied six varieties or lines of Western Canadian rye and found that the level of trypsin inhibition ranged from 22.5 - 52.5% of normal enzyme activity. Chernick *et al.* (1948) attributed pancreatic hypertrophy and decreased growth rates of poultry and rats to the high levels of trypsin inhibitor present in their diet of soybean meal, but Minja (1970) could find neither decrease in growth nor pancreatic hypertrophy in chickens fed diets containing high (50%) levels of rye. Trypsin inhibitors, due to their proteinaceous nature, are heat-labile but neither Minja (1970) nor Moran *et al.* (1969) could find any improvement in the biological value of rye after heat treatment or autoclaving. To date there seems to be very little evidence that trypsin inhibitors are the primary cause of the feeding problems associated with rye (Minja 1970).

iii) Alkyl-resorcinols, are compounds consisting of a phenolic moiety with a long carbon chain attached in the 5 position, they are relatively widespread throughout the plant kingdom (Levin 1971). An alkyl-resorcinol was isolated from the pericarp of rye by Wieringa (1967) and it was postulated that this compound was associated with the growth inhibition caused by rye diets. Alkyl-resorcinols had been identified earlier in wheat bran by Wenkert *et al.* (1964), but the levels found in rye were twice as high as those in wheat, up to 0.5%. Munck (1972) found that the average alkyl-resorcinol level of a number of rye varieties was 2-3 times higher than the mean level of wheat varieties.

Wieringa (1970) found that supplementation of diets with the alkyl-resorcinol containing fraction of rye oil resulted in decreased consumption and lower growth rates of rats. Although rye oil has a bitter taste, low palatability was not responsible for decreased consumption. Experiments were performed which involved administering the rations by stomach tube thus overcoming any palatability effects. The diet still produced decreased consumption suggesting that adverse metabolic disturbances were in some way influencing feed uptake (Wieringa 1967). Munck (1972) found an inverse relationship between body-fat gains and units of alkyl-resorcinol consumed in diets given to mice and implicated alkyl-resorcinols as inhibitors of fat absorption. Zillman *et al.* (1974) extracted the alkyl-resorcinols from triticale but could demonstrate no adverse effects of a high alkyl-resorcinol diet on weight gains of mice. Similarly, Friend (1970) could find no inhibitory effect of rye bran when added to the basal diets of rats. It is possible that in these last reports the adverse effects of rye may have been diminished by the high levels of oil used in the diet (see Haeberle 1974). Although Haeberle deliberately used low levels of oil to avoid this possibility he could find no relationship between the level of alkylresorcinol in diets fed to mice and either consumption or their growth rates.

Munck (1972) points out that in 1964 Virtanen reported on some research of organic sulphur compounds in plants in which he reviews certain inhibitors to the disease snow mould (*Fusarium nivale*) which belong to a class of compounds known as benzoxazolines and are found at high levels in rye, and also in wheat endosperm. Their physiological effects on animals are not known, but along with the other substances present in the rye kernel, they remain potentially responsible for the low feeding value of rye. More chemical studies are necessary and further feeding trials need to be carried out before the factor(s) responsible for the feeding problems associated with rye can be fully elucidated.

2.3.B The nutritive quality of rye

Many experiments have demonstrated the high biological value of rye proteins, Munck (1972) found that rye had a high protein efficiency ratio (P.E.R.) than wheat, similar results were reported for rye bread compared to wheat bread by Strømnaes and Kennedy (1957) with rats and by Kofrányi and Müller-Wecker (1960) for humans. Kihlberg and Ericson (1964) found that rye flour promoted greater weight gains in rats than wheat flour and reviewed a number of articles that report on the superiority of rye protein over wheat protein. It is also well documented that the amino-acid balance of the rye kernel is superior to wheat having

TABLE 2. DIFFERENCES BETWEEN RYE AND WHEAT (RYE - WHEAT) IN THE LEVELS OF NINE AMINO-ACIDS AS REPORTED FROM THREE DIFFERENT SOURCES.

AMINO - ACID	REFERENCE AND UNIT OF MEASUREMENT		
	BARTNIK(1965) gm Aa/16 gm N.	MUNCK(1972) gm Aa/16 gm N.	EWART(1967) gm Aa/100 gm Total Aa.
ARGININE	+2.0	+0.36	+1.0
HISTIDINE	-0.5	+0.02	-0.1
ISOLEUCINE	-0.5	-0.05	0
LEUCINE	-0.8	-0.43	0
LYSINE	+1.0	+0.87	+1.3
METHIONINE	-0.4	0	+0.4
PHENYLALANINE	0	+0.21	-0.2
THREONINE	+0.5	+0.48	+0.7
VALINE	+0.5	+0.25	+0.7

Note; Bartnik and Munck used whole grains,Ewart used flour.