3:35 **The Use of Wheat in Modern Feeding Programs for Other Poultry and Game Birds**
Dr. Rollin H. Thayer, Professor of Poultry Science, Department of Animal Sciences and Industry, OSU

THURSDAY EVENING

7:00 Banquet—Student Union Ballroom
Master of Ceremonies: Dr. W. F. Taggart, Director for Extension Work, College of Agriculture, OSU
8:00 **Welcome to Oklahoma State University**
Dr. Robert B. Kamm, President, OSU
8:15 **Greetings from the Oklahoma Wheat Commission**
Mr. Dean Carter, President, Oklahoma Wheat Commission
8:20 **Factors Affecting the Availability of Wheat for Livestock Feeding**
Mr. Clarence Palmby, Assistant Secretary of Agriculture for International Affairs and Commodity Programs, USDA, and President, Commodity Credit Corporation

FRIDAY MORNING

Chairman: Dr. Ronald R. Johnson, Professor, Department of Animal Sciences and Industry, OSU
8:45 **Rumen Malfunctions—Acidosis Problems With High Grain Rations**
Dr. Robert H. Dunlop, Professor and Head, Department of Veterinary Physiology, University of Saskatchewan
9:30 **Metabolic Aspects of Feeding Wheat to Beef Cattle**
Dr. R. R. Oltjen, Leader, Nutrition Investigations, Beef Cattle Research Branch, Agricultural Research Service, Beltsville, Md.
10:35 **Nutritive Value and Suitable Levels of Wheat for Dairy Cattle**
Dr. Donald E. Waldern, Research Scientist, Dairy Cattle Nutrition, Canada Department of Agriculture, Agassiz, British Columbia

FRIDAY AFTERNOON

Chairman: Dr. Donald R. Gill, Associate Professor, Department of Animal Sciences and Industry, OSU
1:15 **The Use and Value of Wheat in Beef Cattle Feeding**
Dr. John R. Brethour, Associate Professor, Beef Cattle Research, Fort Hays Station, Kansas State University
2:00 **Comparative Net Energy Values of Rations Containing Wheat and Other Grains for Beef Cattle**
Dr. G. P. Lofgreen, Nutritionist, Imperial Valley Field Station, University of California

Opportunities and Obstacles in Wheat Production and Improvement

Louis P. Reitz

Availability of Wheat for Feed

The amount of wheat grain that is fed to livestock varies widely from year to year but it is a relatively small portion of the total crop. Even so, the tonnage is considerable. Since 1964, the average has been about 110 million bushels per year (Table 1) or 3,300,000 tons. Possibly, 200 million bushels of the 1969 crop will be fed (31). In the case of corn, one-half of the crop is fed on the farm where grown; however, only about one-thirtieth of the wheat crop is so utilized. In the Atlantic States (but nowhere else in the United States) about 10% of the wheat has been fed on the same farm where produced. States where more than 3 million bushels of home-grown wheat were fed in 1968 include Pennsylvania, Ohio, Indiana, Michigan, Missouri, Kansas, Montana, and Idaho (6).

The byproducts of milling — mainly bran and shorts — must be added to the quantity of grain that is fed to express the total impact of wheat as feed. The byproducts have been estimated at about 4,500,000 tons annually (Table 1) (1). This is 25% more in total weight than the grain that is fed. Hence, the combined estimates show that wheat annually contributes nearly 8 million tons to the feed supply.

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Table 1. Wheat: Supply, distribution and prices, average 1964-68 and Annual 1966-69.
(From Wheat Situation 211)

Item	Average 1964-68	1966	1967	1968[1]	1969 Projected
	Year beginning July				
	Million bushels				
Supply					
Beginning carryover	643.6	535.2	425.0	539.4	819
Production	1,401.9	1,311.7	1,522.4	1,576.2	1,459
Imports[2]	1.2	1.7	.9	1.1	1
Total supply	2,046.7	1,848.6	1,948.3	2,116.7	2,279
Domestic disappearance					
Foods[3]	513.1	501.9	519.2	519.8	525
Seed	67.8	78.4	71.5	61.6	55
Industry	.1	.1	.1	.1	---
Feed (residual)[4]	110.2	98.9	57.0	172.5	200
On farms where grown	(40.1)	(26.1)	(42.9)	(58.6)	
Total	691.2	679.3	647.8	754.0	780
Available for Export and Carryover	1,355.5	1,169.3	1,300.5	1,362.7	1,499
Exports[2]	728.4	744.3	761.1	544.1	600
Commercial, incl. barter	(322.6)	(438.8)	(366.9)	(293.2)	
Total disappearance	1,419.6	1,423.6	1,408.9	1,298.1	1,380
Ending carryover	627.1	425.0	539.4	818.6	899
Privately owned—"Free"	(194.5)	(223.7)	(216.2)	(202.9)	
Wheat millfeeds (1,000 tons):	4,700.	4,499	4,490	---	---
	Dollars per bushel				
Price Support					
National average loan rate	1.26	1.25	1.25	1.25	1.25
Average certificate payment	.50	.59	.48	.55	.65
Season Average Price Received					
By non-participants	1.39	1.63	1.39	1.24	1.23
By program participants	1.89	2.22	1.87	1.79	1.88

[1] Preliminary.
[2] Imports and exports are of wheat, including flour and other products in terms of wheat.
[3] Used for food in the United States and U.S. territories, and by the military both at home and abroad.
[4] Assumed to roughly approximate total amount used for feed, including amount used in mixed and processed feed.
[5] Average is for 1962-67. Data from 1969 Suppl. to USDA Stat. Bull. 410.

Statistics on feed use of wheat must be used with caution. USDA values of grain fed are derived partially as a residual after other uses have been apportioned and, therefore, are subject to several unknown factors.

The feeding of wheat depends upon how useful it is for various classes of animals and whether supplies of wheat are available at competitive prices. All my life I have been told that wheat was too dear a product to feed to livestock. This, obviously, is not quite the case. Wheat as feed has been a secondary use; the margin of price and hence, choice, generally has gone in favor of corn, sorghum, barley, and oats, all traditional feed grains.

Table 2. Grain Crop Production in the United States, 1960-69
(From CRPR 2-1 69).

CROP PRODUCTION, UNITED STATES[1], 1960-69

Year	Corn, grain	Oats	Barley	Sorghum grain	Feed grains[2]	Rye
	1,000 bushels				1,000 tons	1,000 bushels
1960	3,906,949	1,153,332	429,005	619,954	155,503	33,108
1961	3,597,803	1,010,314	392,441	480,208	139,768	27,336
1962	3,606,311	1,012,197	427,726	510,284	141,725	40,698
1963	4,019,238	965,510	392,833	585,394	153,806	29,178
1964	3,484,253	852,257	386,059	489,796	134,174	32,476
1965	4,084,342	926,851	392,279	672,698	157,443	33,223
1966	4,117,355	801,327	393,186	714,992	157,563	27,775
1967	4,760,076	789,196	372,898	755,936	176,025	24,154
1968	4,393,273	939,228	422,959	739,695	168,902	23,365
1969	4,577,864	949,874	417,156	743,124	174,197	31,405

Year	Wheat: Winter	Wheat: Durum	Wheat: Other spring	Wheat: All	Buckwheat	Rice	Food grains[1]
	1,000 bushels					1,000 cwt.	1,000 tons
1960	1,111,403	34,361	208,945	1,354,709	847	54,591	44,318
1961	1,074,807	21,339	136,213	1,232,359	864	54,198	40,467
1962	822,887	70,260	198,811	1,091,958	828	66,045	37,221
1963	914,090	51,427	181,304	1,146,821	952	70,269	38,758
1964	1,020,987	68,146	194,238	1,283,371	1,020	73,166	43,092
1965	1,017,085	69,866	228,662	1,315,613	[3]	76,281	44,212
1966	1,062,493	62,638	186,571	1,311,702	---	85,020	44,380
1967	1,206,808	66,443	249,131	1,522,382	---	89,379	50,816
1968	1,235,063	99,501	241,687	1,576,251	---	104,075	53,146
1969	1,147,646	106,319	204,907	1,458,872	---	91,303	49,210

[1] Does not include Alaska and Hawaii.
[2] Corn for grain, oats, barley, and sorghum grain.
[3] Estimates discontinued.
[4] Wheat, rice, rye, and buckwheat.

My objective is to present background, outline the status of the problem of feeding wheat, and discuss improvement in terms of supplies, yields, costs, and production.

U.S. wheat producers serve four markets: 1) domestic food; 2) export; 3) feed; and 4) industry. In a long view of opportunities, Palmby (18) concluded that "if we are to make anything like full use of our present capacity to produce wheat, we will have to market increasing amounts as livestock and poultry feed." He emphasized feed usage both domestically and as a part of our exports of wheat.

We can grow much more wheat than we can use for food or export. Our allotment this year is down to 45.5 million acres. As recently as 1967, we harvested 58.7 million acres and in 1949 we harvested 75.9 million acres. The average acre yield for the U.S. has more than doubled in the last 50 years. The fact is inescapable that we have a very great potential for wheat production. Only four wheat crops in the last 25 years

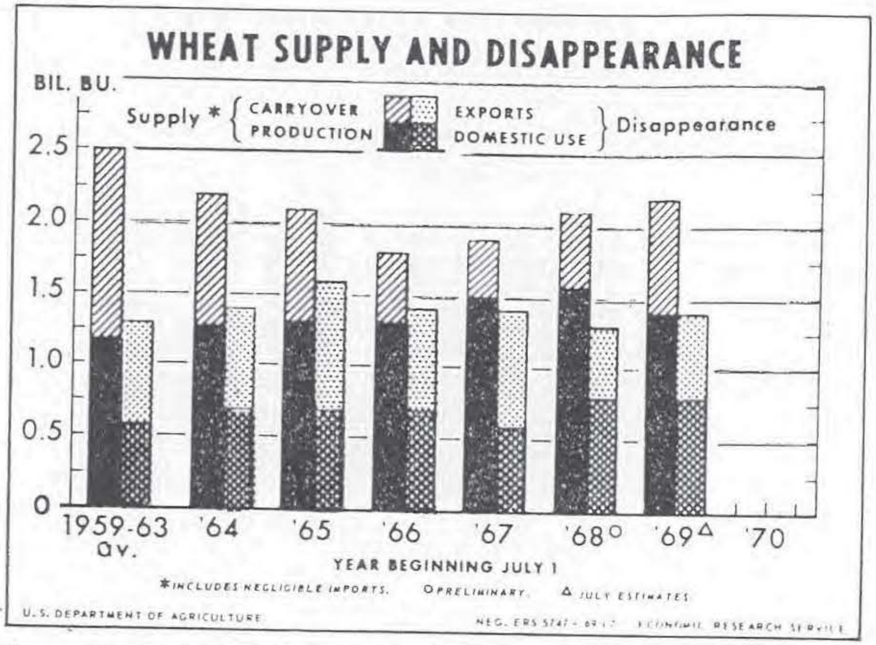

Figure 1. U. S. Supply and Disappearance of Wheat, 1959-1969.
(From Wheat Situation 209).

have fallen below a billion bushels. The last three averaged more than 1.5 billion bushels. By contrast, we have grown feed crops in large amounts as follows: corn, 4.5 billion bushels; oats, 0.9 billion; barley, 0.4 billion; and sorghum, 0.7 billion. Bushels converted to their ton equivalents were 174 million tons in 1969 for feed grains combined and 49 million tons for food grains. The latter includes wheat, rice, and rye. Wheat *vs* feed grains for 1960 to 1969 is shown in Table 2 (23). A return to former acreages of wheat could readily increase output 50% in the United States.

The relationship between wheat and feed grains is complicated by commodity programs. This has been discussed at length by many competent people. Hadwiger (11) says: "Every bushel of wheat not used for food is a potential addition to feed grain supply. Therefore, programs for reducing wheat production and for increasing food outlets for wheat have been of direct concern to feed grains producers. — Assuming a surplus of wheat on the cash food market, wheat growers have had even more reason than feed grains producers to be concerned about the relationship of feed grains and wheat, because the price of the entire production of wheat in a free market would in that event be its feed value."

The wheat supply and disappearance situation is summarized in Figure 1 (31) and Table 1. The combined production and carryover

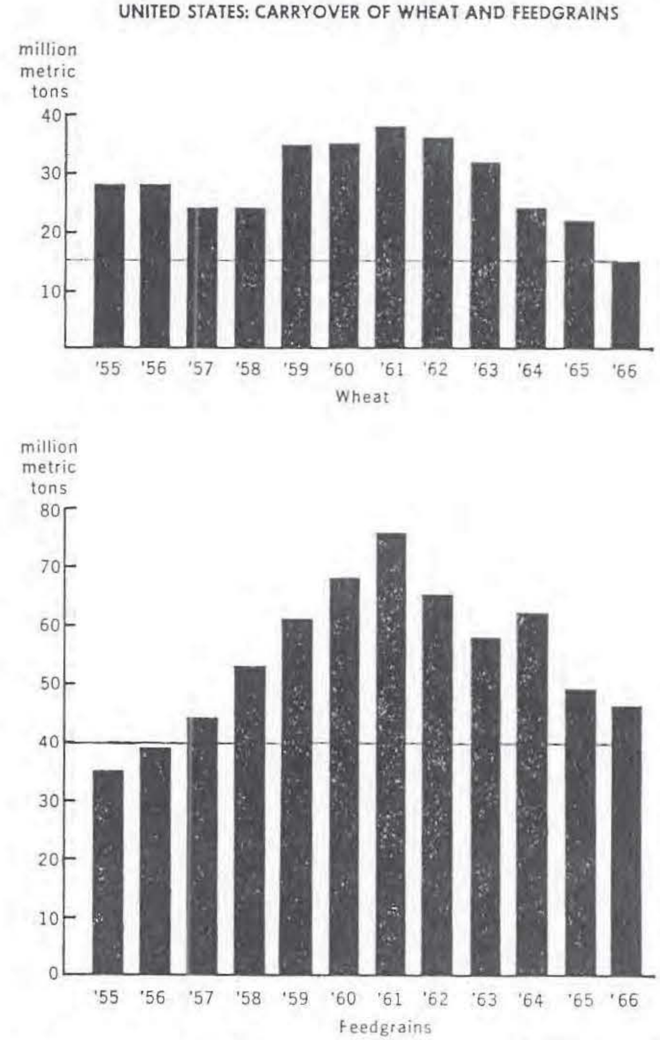

Figure 2. Carryover of Wheat and Feedgrains in the U.S., 1955-1966.
(Freeman).

have approached or exceeded 2 billion bushels in most years and reached 2.5 billion in one year. This was during years when exports were at an all-time high. Feed grains, likewise, have been carried over in substantial amounts. Figure 2 compares the carryover of wheat and feed grains (8). I do not know what amount should be carried over as a safety reserve. Some have said a one-year supply is needed. Sixteen million tons (600 million bushels) of wheat would be required and for feed grains 45 million short tons. If one draws a line from left to right perpendicular

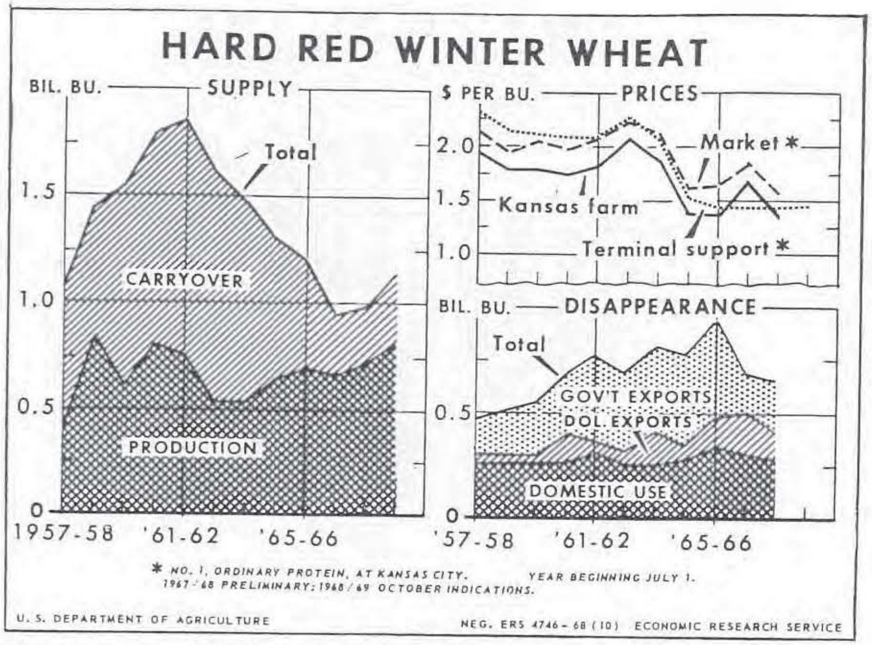

Figure 3. **Hard Red Winter Wheat Production in the U.S., Prices and Disappearance, 1957-1968.**
(From Wheat Situation 206).

to the 15 million point for wheat and about 40 million for feed grains on Figure 2, we see that there was excess every year except one for wheat, and excess every year except two for feed grains. So, we are producing now at a moderate level commensurate with a regular outlet for wheat as feed. The amount of excess increased and declined in the same years which shows a competitive situation rather than a complementary one. There could be a great excess for feed in the United States with expanded acreage or reduced exports.

Where have our supplies of wheat come from? A series of graphs will show this clearly. Hard red winter is the concern in Figure 3, hard red spring is shown in Figure 4, durum in Figure 5, eastern soft in Figure 6, and western in Figure 7 (9). The current situation is summarized in Table 3 for 1969 and an estimate is given for 1970 (31). Hard red winter wheat grown mainly in the central and southern Plains, has amounted to about three-fourths of the total carryover. It is also the major export class, with more shipped than all other classes combined. This class has also tended to dominate the price determination. Western wheat is very active also in export; only about one-sixth of the western wheat produced is used domestically. Hard red spring wheat mainly grown in the North-central states, is normally in great demand domestically and for dollar

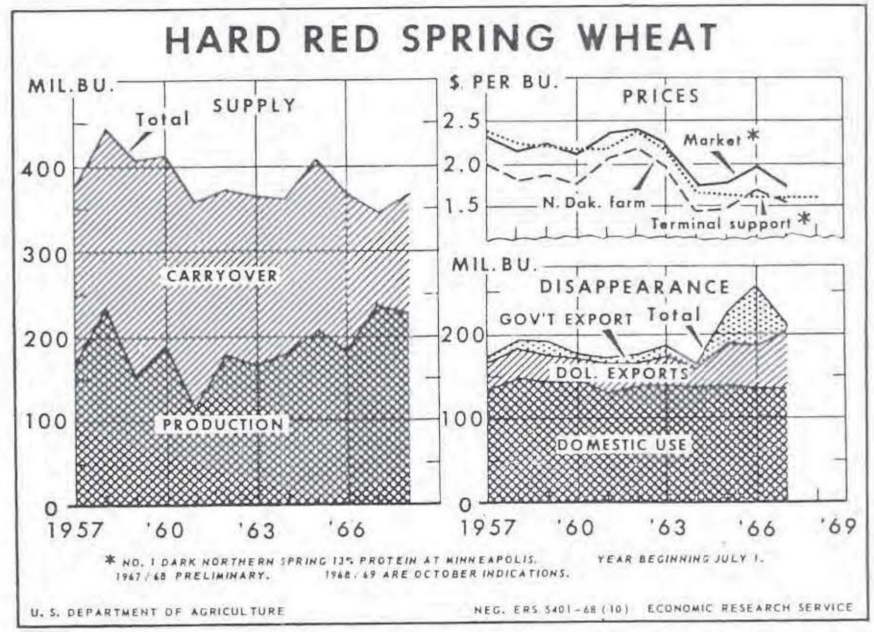

Figure 4. **Hard Red Spring Wheat Production in the U.S., Prices and Disappearance, 1957-1968.**
(From Wheat Situation 206).

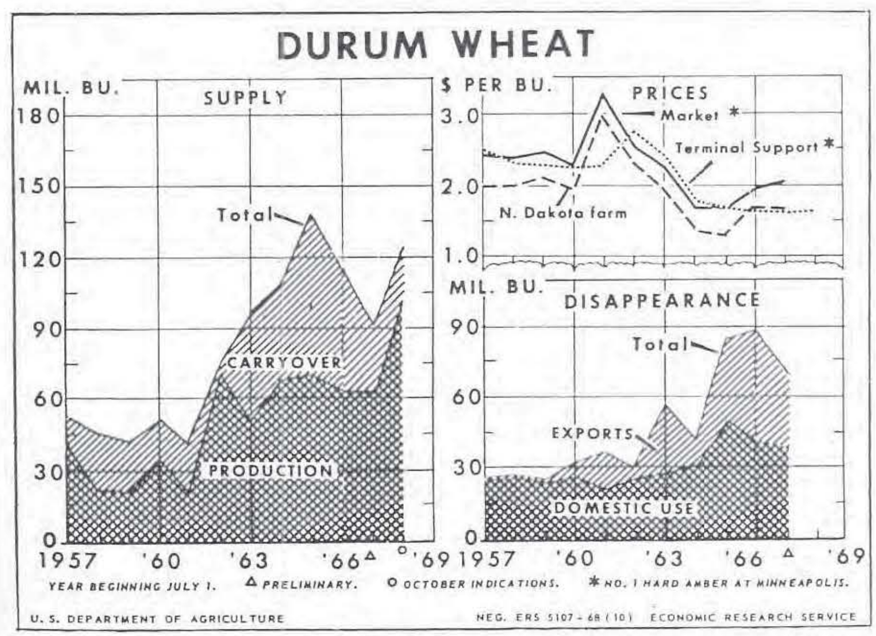

Figure 5. **Durum Wheat Production in the U.S., Prices and Disappearance, 1957-1968.**
(From Wheat Situation 206).

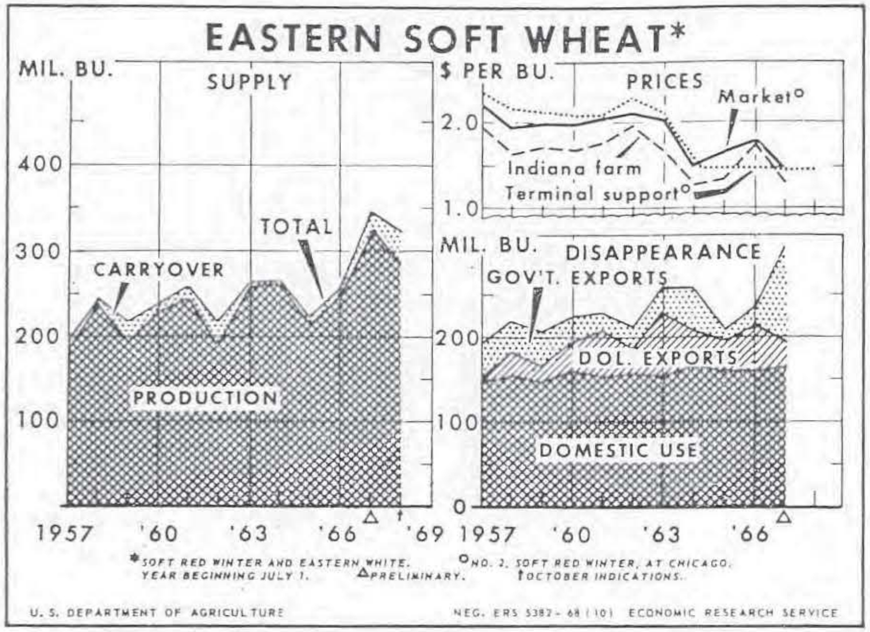

Figure 6. **Eastern Soft Wheat Production in the U.S., Prices and Disappearance, 1957-1968.**
(From Wheat Situation 206).

exports. Only in recent years has there been an excess of durum, a kind of wheat also grown mainly in the Northcentral states. The eastern soft wheat has generally been utilized domestically, partly because of its physical position in heavy-consuming areas and because it has been used liberally for feed (10).

Average U.S. crop yields in pounds per acre harvested for the 10 years 1960-1969 are as follows: rice, 4045; corn, 3920; sorghum, 2682; barley, 1820; wheat, 1583; oats, 1504; rye, 1169 (23). 8hese weights include hulls in the case of rice (about 20%), barley (about 15%), and oats (about 25%). Corn and rice tend to be grown under the most uniformly favorable circumstances; the cultural conditions for the others are highly variable.

The yield comparisons for four grain crops are made for six States in Figure 8. Corn and sorghum lead in productiveness in all six States. Wheat and barley are about equal unless the hulls of barley are deducted. Even within States, the circumstances for culture often differ so much that valid crop-yield comparisons are impossible from such data. In Kansas, for example, the corn acreage is largely in a rainfall belt exceeding 30 inches and most of the wheat is grown in the area with less than that amount. The acreage of corn in North Dakota is small and in Washing-

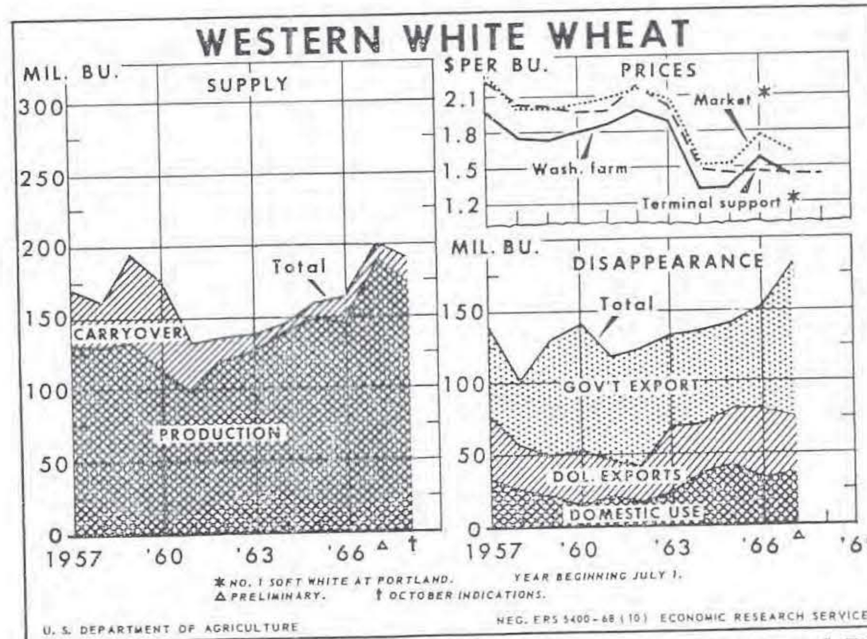

Figure 7. White Wheat Production in Western U.S., Prices and Disappearance, 1957-1968.
(From Wheat Situation 206).

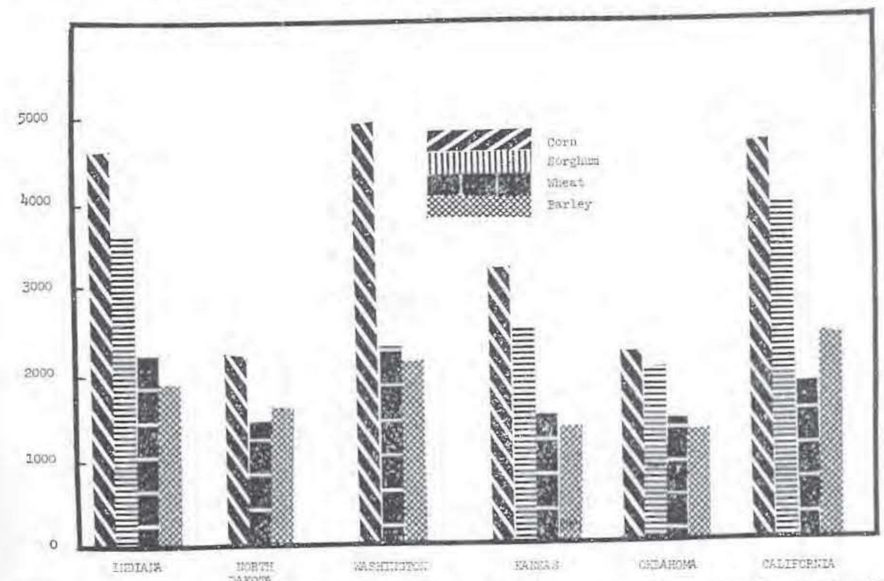

Figure 8. Average Yield (pounds) per Harvested Acre of Four Grain Crops in Designated States, 1960-1969.
(SRS, USDA).

Table 3. June Carryovers of Various Classes of Wheat, 1969 and 1970 Estimates.
(From Wheat Situation 211, p. 7).

Item	June 30 1969	June 30 1970
	Million bushels	
Hard red winter	547	640-660
Soft red winter	33	20-25
Hard red spring	140	95-105
Durum	41	65-75
White	58	50-60
Total	819	899

Table 4. U.S. Average Prices of Wheat and Corn; also Wheat Fed. Nine Months in 1968-69.
(Wheat Situation 208, p. 6).

1968/69	Farm price per cwt. Wheat	Farm price per cwt. Corn	Wheat relative to corn	Wheat fed
		Dollars		Million bushels
July-Sept.	2.00	1.81	+.19	115
Oct.-Mar.	2.12	1.88	+.24	45

ton very small and is confined to the areas with the highest number of heat units, higher rainfall, or which are under irrigation. The fact remains, however, that when a choice is warranted, corn and sorghum get the nod for high yielding feed grain acres. Even when wheat grain yields would indicate the crop was not competitive, farmers for other reasons may grow it. The grazing value alone may be decisive. In fact, two-thirds of the wheat in Kansas, Oklahoma, Texas and the Southeast is grazed to some extent in most years.

Prices and Competitive Values

The price of wheat has declined in recent years for all of the market classes reviewed above. This has caused numerous management questions to be raised. One of these is: Has the price of wheat been reduced to a level at which its value for feed will be a dominant factor? The relationship of wheat to corn prices in 1968-69 is compared in Table 4 (31). The spread is narrow.

A recent compilation of break-even points for Pacific Northwest wheat and three feed grains for five classes of animals shows that under present barley-wheat supplies and prices, the PNW is in a very favorable position relative to livestock feed costs in other regions (except lamb) (Table 5) (17). Prices of $40 and $50 per ton for wheat represent $1.20 and $1.50 per bushel, respectively.

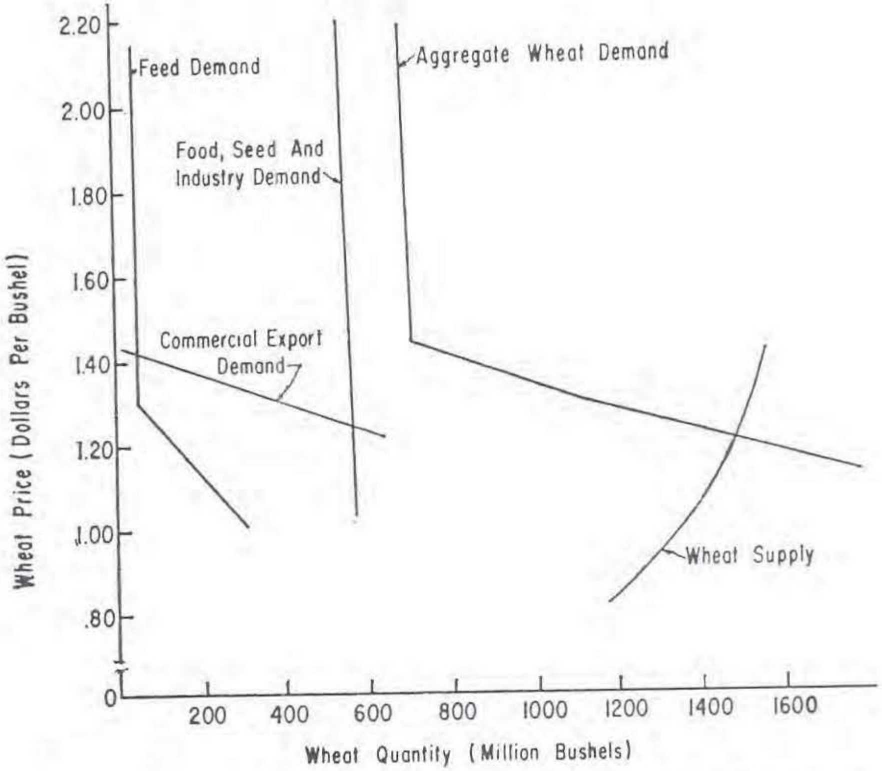

Figure 9. Estimated U.S. Aggregate Wheat Supply, Demand and Three Major Demand Components for 1967.
(From Tweeten, p. 15).

Price has a slight, almost negligible, effect on the amount of wheat used for food. The same is true for seed although these two uses are quite independent. In contrast, the demand for wheat used for feed is

Table 5. Break-even Western Soft White Wheat Prices to Give Nutritional Equivalent at Various Sorghums, Corn, and Barley Prices.

Grain; $ Per T		Feeder Cattle	Dairy Cattle	Hogs	Lamb	Poultry
Sorghum:	$42	$47	$42	$42	$40	$38
	44	49	44	44	42	40
Corn:	$42	44	42	42	38	38
	44	46	44	43	40	40
Barley:	$42	47	42	47	40	47
		49	44	49	42	49

SOURCE: Issues and Alternatives in Wheat Production and Marketing. Oregon State University, Corvallis, Oregon. Jan. 1970, 23 pages.

highly responsive to price; export demand is a mixed response to dollar markets and government stimuli. The Oklahoma Agricultural Experiment Station published a study on these relationships which I commend to you (30). One of the models (Figure 9) is a brief summary. It will be seen that the demand for feed changes but little at moderate prices but increases rapidly after the price reaches a low, critical, presumably competitive point. The commercial export demand may vary over a wide quantity. Food, seed and industry uses are inelastic at something just below 600 million bushels. The autonomous government demand (about 100 million bushels) is not shown but is included in the aggregate. Where the line for aggregate demand intersects the supply arc (Figure 9), we see approximately free market equilibrium prices and quantities as follows: $1.20 per bushel; 565 million bushels for food, seed, and industry; 135 million for feed; and 780 million for export (total 1,480,000,000 bushels). The model requires many rigid assumptions but it illustrates interactions of some of the factors involved and helps assess how society may obtain the greatest net benefits from various kinds of programs.

There are, of course, economic limits to the production of wheat. Net returns are closely related to yield level when total inputs remain about the same. Increased operations representing improved technology generally mean increased costs which can only be recouped if the total returns are increased substantially above costs. Size of operation is often thought to be related to efficiency but a balanced set of machinery and manpower can introduce stability into the cost per bushel beyond which an increase in size of units may not show further savings. This is illustrated by a study in western Nebraska (33) wherein the cost per bushel did not change after a size class of 250-300 acres of wheat was reached up to 1000-acre units.

A major element of concern in planning to use wheat for feed is the regularity of supply at the regional, local, and farm level. Wheat yields vary widely, especially in the Plains (13), as can be seen from Figure 10a (26). More stability is noted in the Pacific Northwest and the eastern States. Corn yields also vary, and in a similar manner although corn is not grown so extensively in the higher risk areas (Figure 10b). The percentage of the wheat acreage abandoned reaches high levels in some years and when adverse weather is the main cause, large areas in several states may be affected in the same year. A graph illustrating this situation appears as Figure 11 (15). Of course, all feed is in jeopardy over wide areas when severe weather occurs. Livestock men are familiar with this problem and the disruptive consequences of it. Feed reserves, dependence on alternative feed sources, and herd thinning are resorted to for relief.

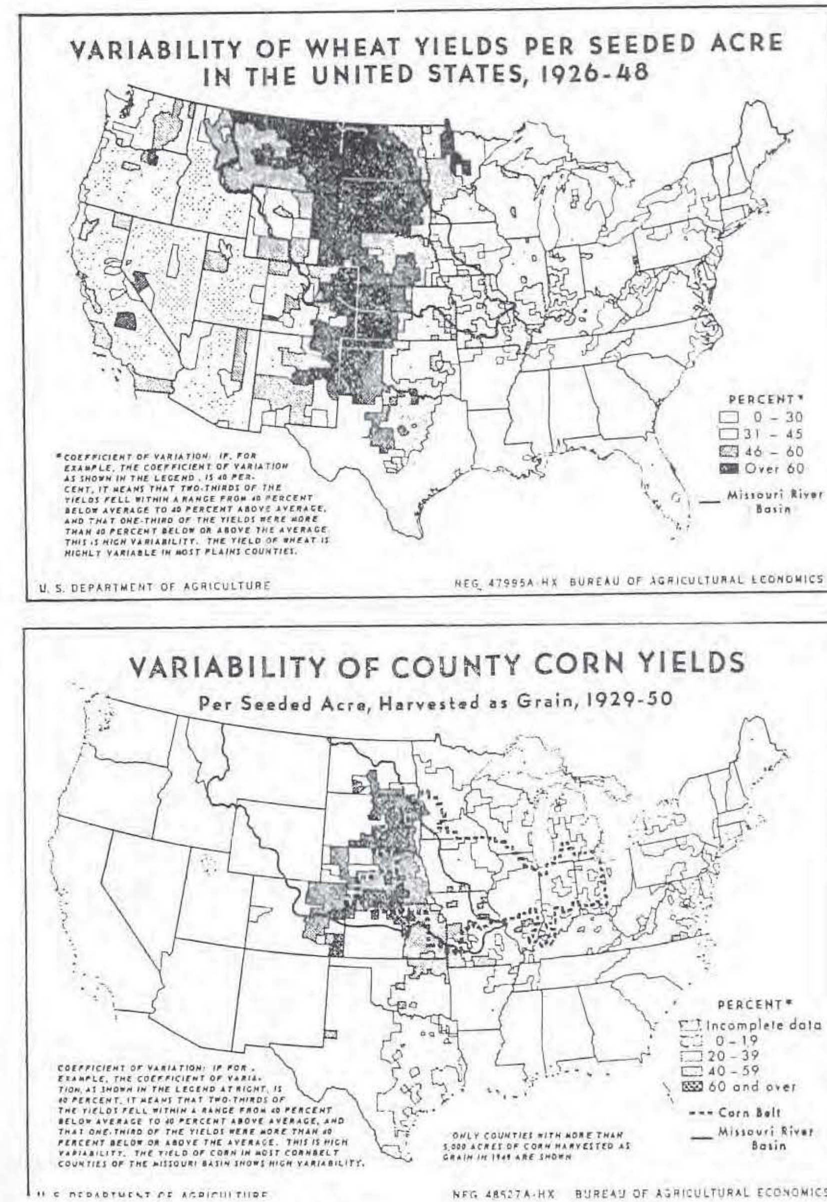

Figure 10. Variability of Wheat (a) and Corn (b) Yields.
(From Nebraska Bulletin 422, pp. 32-33).

There are two ways to think about wheat as a feed grain: 1) an incidental use of the crop or 2) planned as a regular part of the feed supply. In either case, basic nutritional and economic factors about the

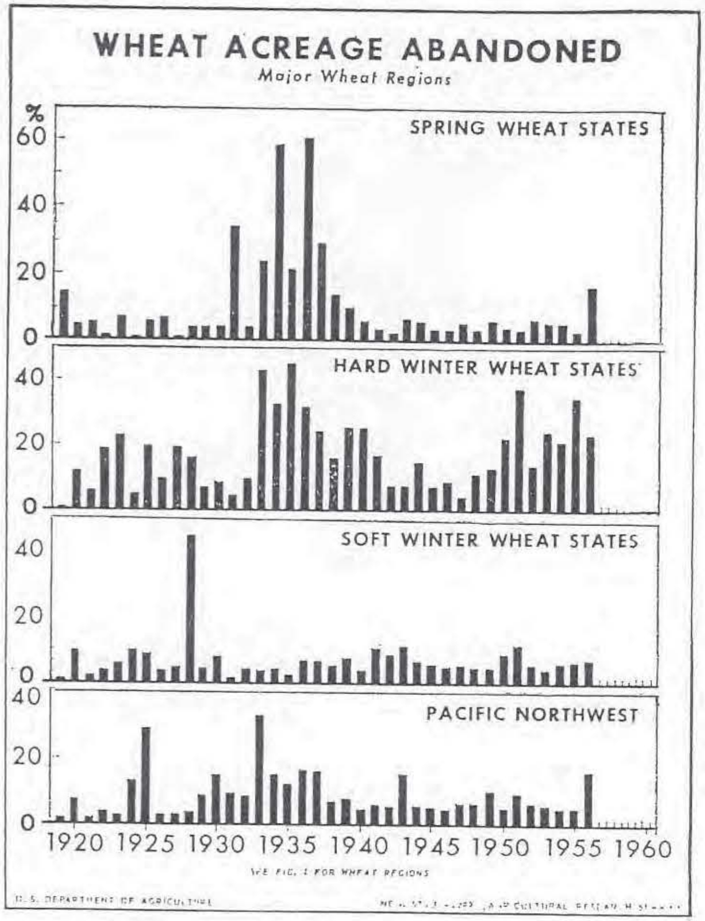

Figure 11. Percentage of the Wheat Acreage Abandoned in Four Regions of the U.S., 1919-1956.
(From Nauheim et al, p. 22).

use of wheat in rations of many kinds are needed and it is indeed appropriate to have the known information summarized. Millfeeds have always been in the second category while direct use of grain for feed has tended to be intermittent. Even when supplies have been burdensome and prices depressed, a need to supply other nations, borne of humanitarianism, opportunism in marketing, or defense have drained away the supplies often at attractive prices. Farmers, the grain trade and government programs have all tended to hold supplies away from feeders, either by the hope for good prices, by various guarantees, or by the position where the grain is stored. Some efficiency in marketing wheat for feed is thereby lost.

It has been argued that varieties should be bred specifically for feed. This may be valid when we learn what to breed for but as of now breeders have nothing to guide them toward a type not also compatible with normal objectives for food usage. It has been suggested that feed wheats be marked a distinctive color such as green, blue or purple. This could be done but it would impede the movement of such wheat into other appropriate markets. There are no convincing data that high yields, good milling and baking quality, and satisfactory feed values are incompatible objectives.

Planning for the production of wheat for feed involves availability of efficient practices and responsive varieties which together lead to high yields and low costs. Except for the constraint of milling and baking quality, most of the requirements and decisions for producing wheat for feed and food are the same. In fact, when specific information about the feed quality requirements of wheat become known, both quality constraints may about balance out. Some understanding of the problems associated with producing wheat seems pertinent.

Improved Yields by Cultural Practices

The culture and improvement of wheat have been discussed by so many workers that only a partial review can be achieved here. The excellent treatments of cultural problems by Schlehuber and Tucker (22), Leonard and Martin (14), Peterson (19), and Nielsen (16) provide a good basis for understanding the problems, methods, and opportunities for improving the yield and stability of wheat production through cultural practices in North America. A still broader view of dryland wheat production has recently been published (5).

Under humid conditions in North America, or with irrigation, wheat is generally grown in rotation with a legume or grass sod crop or with one or more intertilled crops such as corn and soybeans. In the Southeast, much interest has been shown in a two-crop-per-year system by which a summer crop of soybeans or corn is followed by a winter crop of wheat. The success of rotations is related not so much to the fact that a sequence of crops was grown but to the total return from the diverse crops in contrast to monocrop culture. The specific response of wheat is related to weed and other pest control, availability of plant nutrients and soil moisture, not overlooking subsoil moisture. Wheat after sweetclover or alfalfa frequently is disappointing. One cause for disappointment is a dry subsoil. Continuous wheat, often decried, is a practical way to grow wheat, and the yields may be maintained, even increased, over time by proper soil fertilization, moisture conservation, and weed control. Seventy-two years of continuous wheat in the Magruder plots at Oklahoma State University prove this point (22). In the dryer areas an alternate crop and fallow system, or two years in crop and one of fallow, are widely used. Acreage control programs have induced farmers to fallow more of their land for wheat production. The use of fallow, however, is of great concern to agronomists for, while they see short-term yield benefits, some long-range objectives are sacrificed. The exposure of the soil surface to long periods without vegetative cover favors wind and water erosion. New systems of continuous crop husbandry are being sought by our soil and crop management specialists whereby greater precision in use of fertilizer and other inputs will result in avoidance of the depletive consequences of fallow. These systems are not expected to increase the average yield per harvested acre but should add a degree of permanence to our agriculture.

The use of improved methods of tillage, soil management, and fallow have increased wheat yields and helped to stabilize them in our semi-arid areas. A recent summary of 27 years' trials in North Platte in western Nebraska (24) provides a good example. Alternate wheat and fallow gave a crop every year, whereas continuous wheat failed in 10, or 37% of the years. The average acre yield produced on fallow was over 3 times the average from the continuous wheat plots. However, this is a wider ratio of benefit than fallow usually shows. When N fertilizer was applied, the yield was consistently increased on continuous wheat, averaging 50% more than where no N fertilizer was applied; on fallow the yield was not always improved by N and the average increase was about 10%. Nitrogen in the grain was always increased by fertilization. Even so, the water-use efficiency was in favor of fallow both with and without N. In fact, water use on fallow without N was 40% more efficient than continuous wheat with N in years of 25 to 60 cm precipitation, and was about 80% more efficient when annual precipitation was less than 43 cm. These results suggest that where moisture is erratic, as in the Great Plains, approximately 58 cm or more annual precipitation plus N fertilizer are needed for continuous wheat. The average precipitation-evaporation index is 25.6 with a range of 16 to 31 at this test location.

Also, in these and other trials, it has been shown that plowing, disking, subsoiling, and several other initial tillage practices all give about the same average yields. Stubble mulch is consistently superior to bare fallow when the depression of available N, often associated with stubble-mulch tillage, is corrected. More precision in timing the operations and procedures to obtain the same net results at lower costs are reasonable expectations from present research. Increasing moisture uptake seems paramount.

A farmer has four general ways to increase the use of the rainfall:

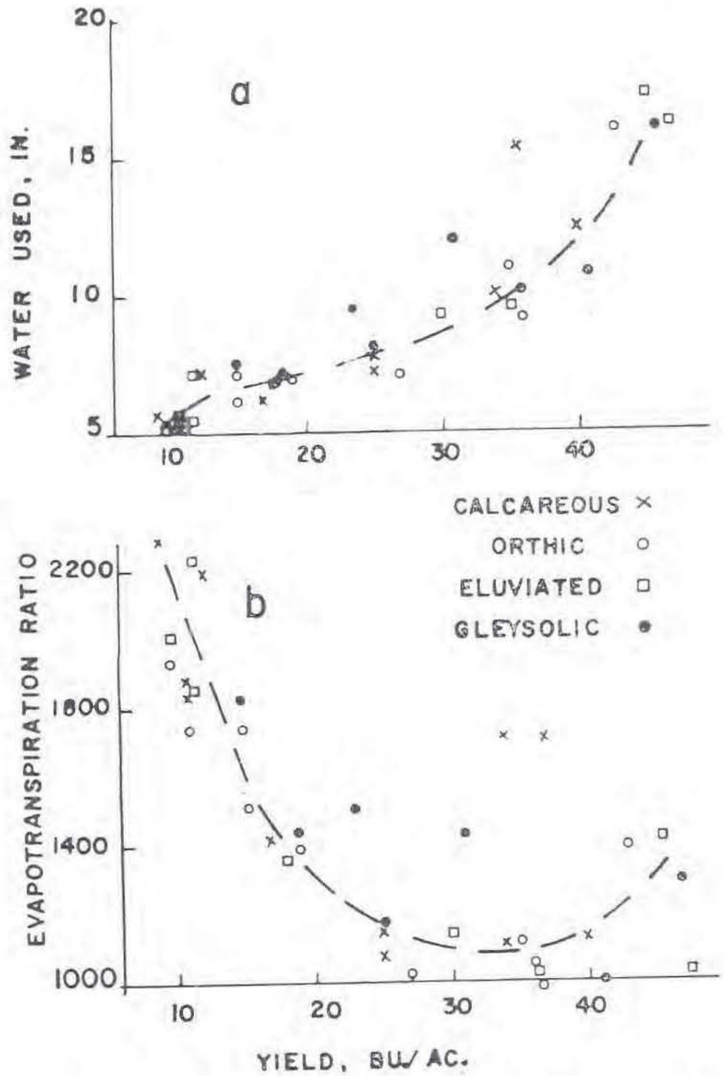

Figure 12. Relationship Between Water Use and Yield (a) and Evapotranspiration Ratio and Yield (b) for Thatcher Wheat in Central Saskatchewan (12).

1) alter the surface to increase infiltration; 2) provide more time for water to infiltrate; 3) manage his cropping system to take advantage of the seasonal distribution of the rainfall; and 4) irrigate.

In the southern Great Plains, about 7½ inches of water are used before any wheat grain can be realized, and each additional inch of water produces about two bushels of wheat. ("Inches of water" means water removed from soil and net of precipitation during the life of the crop.) Five inches and 3.4 bushels are approximate values for Saskatchewan (7, 12) (Figure 12).

In the Pacific Northwest it is said that 4" of water are needed to grow the plant before it produces any seed. Each remaining inch produces seven bushels of wheat in the case of Gaines and Nugaines — six bushels for other varieties. Hence, varietal efficiency can be an important variable. Likewise, fertility may be limiting even under semi-arid conditions, and soil type may be related to both water uptake and storage, and to parent fertility (12).

The predominant loss of water in the Great Plains occurs by evaporation. At the present time, there is no economic method of controlling evaporation for the production of the crops that are normally grown. If conservation practices are to be properly accomplished, an economic method for controlling evaporation for this important agricultural area is badly needed.

Numerous ways to increase the efficiency of precipitation have been investigated. These include ways to reduce runoff and increase penetration, such as stubble and subsurface mulch tillage, contour tillage and terracing, subtilling, etc., and these procedures are beneficial under the right conditions. Chemical fallow is being studied. Chemical weed control in the seeded crop is a wide-spread economical practice. Balancing the available plant nutrients with the expected moisture for the crop is receiving considerable attention and promises to increase yields with greater efficiency, and hopefully, give us more control over protein levels. No other practical means to induce wheat plants to use water more efficiently has been found. Some research is promising with barley and other plants (27, 34). Drought hardening in some wheat varieties has been noted (29).

It is common for a wheat crop to exhaust most of the stored soil moisture by the time of maturity to the depth the roots penetrate. Irrigation as an offset to drought is partially effective. Where water is a resource that is renewed annually, or that is from a supply seemingly undiminished after long usage, irrigation generally is worth the extra cost. Its use brings new competitive factors into play. The water, if limited, may have more value for uses other than feed production. Other crops often yield more than wheat. There is no simple answer to the questions these alternatives pose, but generally agriculture comes off second to industrial and domestic uses when competing for water.

Research on cloud modification and rain-making have given positive results (2). However, when increases in rain have occurred they have

been on the order of 10 to 20% above what might normally have occurred, but results are inconsistent.

We envision a day when there will be more adequate, timely information on still other factors upon which to base wiser decisions. Predictions of probable weather for longer periods of time and the assessment of crop, soil moisture, disease, and insect situations for large regions are active research areas. Reference has already been made to weather modification (2). NASA, USDA, and numerous other research institutions are cooperating in studies of these types. A series of reports from Purdue University are helpful in grasping some of the opportunities and obstacles to the application of such knowledge gained from air- and spacecraft (20). Prediction of outbreaks of rust and insects can be improved by these approaches and the accompanying ground truth.

Breeding for High Yield and Stability

At any point in time it has been short-sighted to say that wheat yields cannot be increased. The 100-bushel per acre yield level is frequently exceeded in our Western states and this barrier was finally broken east of the Rocky Mountains in 1967 by 'Blueboy' in North Carolina, and in 1969 by 'Sturdy' in the High Plains of Texas. A yield of 209 bushels per acre was established in 1965 by 'Gaines' in Washington. These yields, in themselves, are not very important except to show the potentials within present resources. The goal is not simply to match or exceed these high yields occasionally but to stablize production at a level much above the average. We know that this can be done only by breeding efficient, responsive varieties that remain healthy and free from pests all season, and developing soil moisture and fertility management to approach as closely as possible the optimum conditions that are required. Our national average wheat yield has doubled during this century. The yields per acre in California and Arizona have been increased 28 and 37%, respectively, in the last three years above the average for the preceding six years. I would like to see, and believe it realistic to expect, a 50% increase over present national acre yields before the century ends.

What makes varieties responsive and high yielding? Can wheat be made more productive through breeding? Both productivity and stability of yield are modified through the breeding of adapted varieties with necessary resistence to insects and diseases. In an historical sense, basic adaptation of suitable types for each area of the country had to occur before wheat growing could be considered a success. This was represented in the early days by the discovery and wide use of 'Fultz', 'Fulcaster', 'Purplestraw' and a few other varieties in the Eastern states. 'Marquis' spring and 'Kubanka' durum established the crop in Northcentral States.

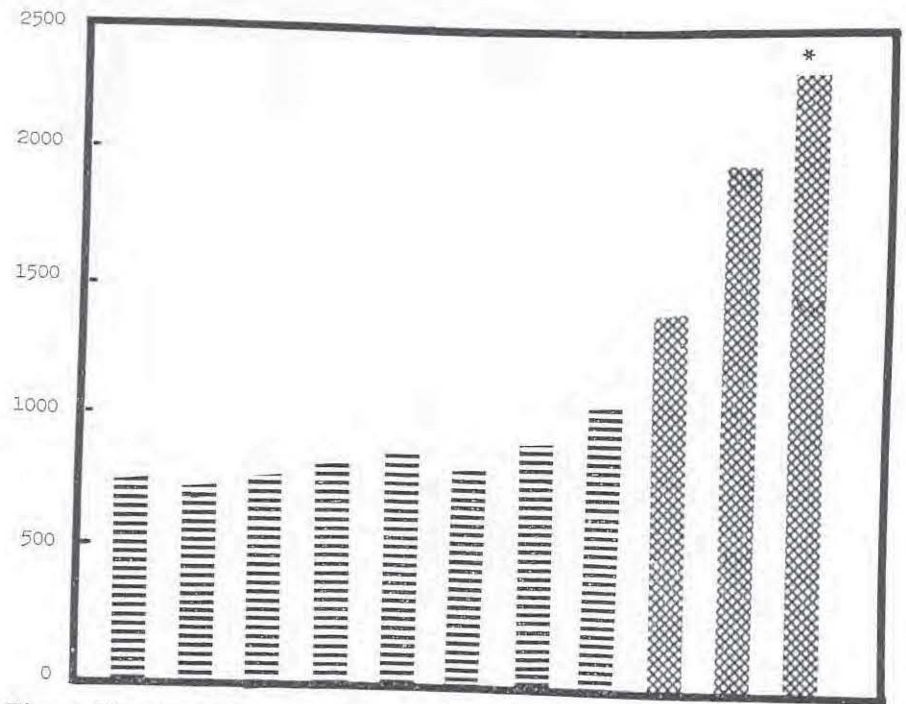

Figure 13. State Average Yields of Wheat in Indiana by Decades, 1870-1966. *1966 Only. Decade 9 Begins the Knox-Monon Era. (Kg. per Hectare)
(From Briggle and Vogel).

'Turkey' was the turning point in the decision for the Central and Southern Plains. Spanish and Australian varieties contributed heavily to the varieties of early-day culture in the Western states. These early-day varieties have all been replaced. In most areas, several replacement cycles have occurred, each representing a better variety form, yet basically embodying the early-day types. Simultaneously, there was resistance to disease and insects bred into many varieties. Yield increments were relatively small. Then, several dramatic events hit all regions—not all at once and not all of one kind. The following illustrate my point: early maturity exhibited by 'Triumph', 'Wichita', 'Scout', and 'Pawnee' in Southern Plains wheats; earliness and short straw found in 'Knox' and 'Monon' in the Ohio Valley; short and early 'Wells' and 'Lakota' durums in North Dakota; semidwarfs with phenomenal yield such as 'Gaines' in the Pacific Northwest and in other varieties in Western states. We do not know exactly why these types were so dramatic. One breeder of considerable experience told me it was "responsiveness to improved management practices." In other words, when these varieties were grown under manage-

ment conducive to high yield, they produced. Yield ceilings imposed by weak straw, late maturity, low tillering capacity, small numbers of fertile florets per head, and deficient seed plumpness and size, were broken. At least some were. Either more seeds, or larger seeds, or both, give higher yield. It really does not matter, except that breeding could be more orderly if we knew.

A clear illustration of responsiveness appears in Figure 13 which shows the average wheat yield for Indiana by decades beginning in 1870 (4). Through eight decades only slight improvement occurred. After that, there was a marked rise. This coincides with the release of Knox and several other superior yielding varieties, but heavier rates of fertilizer and better management practices were also introduced about this time. Was the greater realizable yield due to fertilizer or variety? It is a moot question.

I am convinced that breeding for yield is rewarding but not from a concept of a genetic unit character. There are two ways for yield expression to be viewed: 1) vigor and eventual translocation of metabolites to the seed; and 2) protection against interference with these metabolic processes. The latter is concerned with hardiness, disease and insect resistance, and tolerance to air and soil "pollutants." The former involves rates of DNA and RNA synthesis and cell division, enzyme activities, photosynthetic rates, and efficiency of translocation.

Genetic evidence shows that one or more genes are found on each arm of every chromosome for such yield influencing effects as those enumerated in the above paragraph. The number of possible genotypes is very great and may be calculated for an F_2 population by raising 3 to the power of the gene number. For example, an F_2 derived from crossing two parents differing by 12 independent genes would provide over a half million different genotypes (3^{12}) of which about 4,000 would be different homozygous types. The breeder not only must generate such populations by cross-breeding the right diverse parents, but he must grow a large enough population and find the more productive selections. When desired and unwanted genes are linked, the numbers game gets worse. Because the yield of a single plant is a poor prediction of yield in close-sown plots, and F_2's are single-plant units, the breeder makes little or no progress by selecting for yield in this generation. I think lack of diversity among parents, failure to grow and evaluate large numbers of progeny, and inadequate methods to measure yield potential are the chief obstacles to empirical breeding for yield in wheat. Time (i.e., number of years) compensates for small populations and generally over time the diversity of crosses a breeder studies is relatively great.

Breeding for single gene, specific effects, as in the case of greenbug resistance or rust resistance, is much simpler but becomes less so as the

Table 6. United States Wheat Production Potential as Reduced by Six Kinds of Hazards.

HAZARD	PERCENTAGE REDUCTION
Diseases	14
Weeds	12
Insects	6
Harvest	5
Storage & Processing	4
Violent Weather	5

Based in large part on USDA Handbook 291, "Losses in Agriculture", 1965, 120 pp.

number of specific races or biotypes is increased from which protection is sought. The backcross has been used successfully for adding single traits to varieties but the typical application of the method always narrows diversity. Induced mutations is another method which also suffers from the same limitation.

The evidence to support protective breeding is overwhelming and cannot for a moment be minimized or forgotten. Without resistance to soilborne mosaic, wheat would probably disappear from half of the acreage east of Oklahoma City. The risk from severe stem rust damage is about 1 year in 3 for North Dakota and adjacent areas, yet no appreciable loss has been suffered there in the last 15 years because of the diligent work by responsible breeders who transferred effective genes into varieties to be grown on farms. The Pacific Northwest battled common bunt of wheat for 60 years before enough genes for resistance could be bred into commercial varieties to protect them from infection.

Nor are these jobs finished. The losses from disease (Table 6) show clearly that we lose annually 14% (32), and probably more, from recognizable disease damage and 6% to insects. Violent weather adds at least 5% to these losses. It is perhaps overoptimistic to think all of such loss can be prevented but there is a wide gap to close.

Breeding may fail. For some maladies we have no resistance for exploitation. Three avenues are open: 1) generate new resistance; 2) use chemicals; or 3) grow the crop out of phase to avoid the malady. Germ plasm building is an important sideline of every breeder and a main job of many geneticists. 'Agent', 'Agrus', 'Transfer', and 'Compair' are not very familiar variety names yet all are of tremendous importance as newly generated resistance to the leaf rusts of wheat utilizing resistance from *Agropyron* and *Aegilops*. 'Transec' and 'WRT-235', denote rye-derived rust resisting wheats. In the development of these, both natural and irradiation-induced recombinations are involved. The USDA maintains a collection of common wheats obtained from 75 countries of the world, durum wheats from 60 countries, and other species of wheat from 40. The total now exceeds 22,000 separate accessions. Even so, we believe

that many "old land" varieties should be added to our collection. Improved varieties are replacing them, hence, the natural variation which has evolved in diverse forms grown by farmers all over the world and in wild forms, may quickly be lost unless more collections are preserved. However, no one knows how many collections represent a reasonable number. The use and status of small grain germ plasm were discussed rather fully in a recent review (21).

Mutation-breeding has been mentioned. Irradiation to induce chromosomal breaks from which desired translocations might be obtained is a useful technique. However, useful stocks directly derived from the use of chemical mutagens or rays of various origins are few in number; most of them need clearer documentation. Changes have been induced, so, in time, this source of diversity may be significant in the improvement of wheat for yield or to impart protection.

Agricultural Chemicals

The use of chemicals of all kinds to control pests has come under criticism during the last year or two. Only the uninformed believe that concern about safety of use of chemicals is something new. Federal legislation of 1947 regulating use of pesticides in agriculture and the Miller Bill of 1954 were giant steps in safeguarding our food production and food products. The people's stake in pesticides has received a lot of costly attention. Some long-range effects are showing up and must not be ignored. Hopefully, we learn something annually by which to make use of chemicals even safer.

Efficient, highly productive agriculture without chemicals cannot be predicted with any assurance. Protective chemicals for the control of seedborne diseases and for insect control have been used safely and with profit on wheat for many years. We are beginning to use systemic materials, some effective as seed treatments, which will protect the plant from cereal leaf beetles and aphids for 6 weeks, from powdery mildew for 4 weeks, and eliminate loose smut completely. A chemical to control rust appears feasible and, again, a seed treatment would be ideal. We suffer loss from a number of omnivorous fungi which attack several hosts and exist in innumerable pathogenic culture types. These are very difficult to breed against and perhaps chemicals can be found to help in reducing damage from them.

Some estimates indicate food production might be cut 30% if all chemicals were discontinued. This seems high in the case of current wheat practices, but it is conceivable that a 30% benefit in total production might be achieved through an all-out effort in which chemicals were fully exploited.

Other Opportunities

Growing the crop out of phase to get higher yields by avoiding the malady has very little practical significance now. Seeding and ripening dates for highest yield have largely been determined and adopted. Rotations offer some additional assistance, and supplemented with improved fertilizer and agricultural chemicals, great advances. Large-scale machinery has been the main benefactor to the wheat farmer to provide him with the capability to do the right job in the right way at the right time. Some people have said to me that the farmer would raise better wheat crops if he spent more time in the field, but this is not necessarily true. The use of only 3 man-hours per acre of wheat compared to 15 hours used 50 years ago is related to the high yields of recent times because the work is done so much better. Early maturing varieties escape some hazards and diseases and this illustrates a way breeders have phased the crop to a safer period. A shift from winter wheat to spring wheat in the Pacific Northwest would avoid dwarf bunt but since winter wheat yields more than spring wheat where bunt is not encountered, this becomes an unattractive solution.

Physiological efficiency of wheat and altered plant morphology to increase photosynthesis are being emphasized (3, 28). Wheat ranks relatively low in efficiency of photosynthesis among crops. Through photorespiration wheat apparently is wasteful of metabolites or of its opportunity to fix CO_2, in contrast to corn, sorghum and sugarcane. Physiologists refer to the phenomena as high- and low-compensating responses in terms of the CO_2 equilibrium value each group will establish in a closed, illuminated chamber (28). When corn and wheat are grown together in such a chamber, corn thrives at a CO_2 equilibrium far below wheat, and the latter dies (28). Furthermore, the arrangement and location of chloroplasts in these two groups of plants differ markedly. In corn, the fixation of CO_2 was primarily in plastids surrounding the vascular bundles, and was dispersed in sugarbeet leaves (a high CO_2-compensator species like wheat) (Figure 14). Several investigators are searching for germ plasm in wheat to permit some practical use of these findings and to elucidate the riddles these discoveries pose.

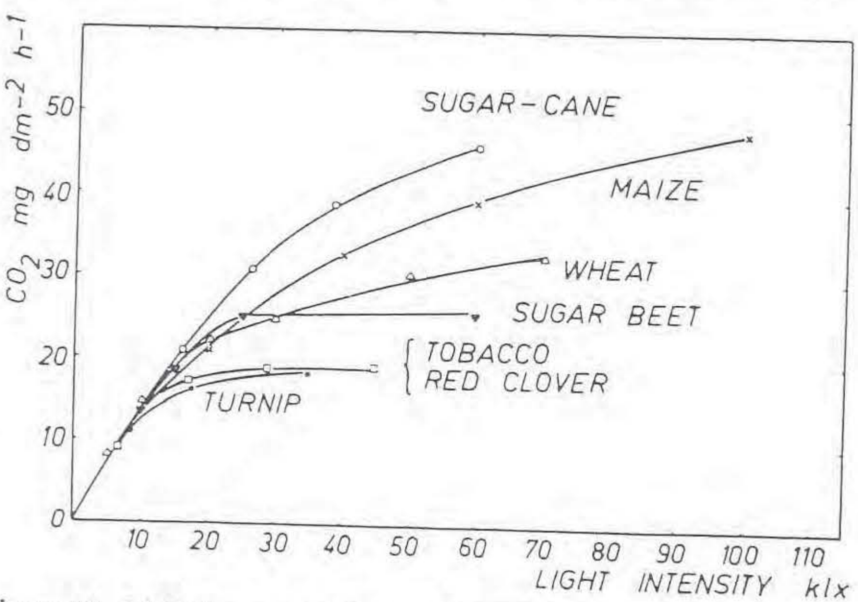

Figure 14. **Light Response Curves of Photosynthesis for Different Crop Plants. Attached Leaves, CO_2 Concentration = 0.03 vol. %, Temperature = 20C (28).**

The problems and opportunities for germ plasm manipulation to obtain higher yields have been reviewed by Sprague (25). Differences in inherent yielding ability in crops may arise, he says, from any one of several deficiencies: 1) energy transfer mechanisms; 2) net assimilation rate; 3) translocation and utilization of photosynthate; 4) nutrient uptake and use; 5) plant growth substances; 6) response under stress conditions; and 7) efficiency of water use. To make progress along these lines requires a capability to identify the desired responses, germ plasm that might be utilized, and a coordinated effort by the breeder and physiologist to create functionally balanced varieties. An empirical approach has largely brought us to the point where we are today, and further progress undoubtedly will come. However, Sprague rightly calls for a major expansion of research in physiological genetics aimed at orderly, scientifically based breeding for yield increases.

Summary

The margin of supply between total wheat production and the amount used for food can be considered available for feed. This is on the order of one-half to one billion bushels in the United States. Competing uses for this wheat are exports to dollar and concessionary markets, relief, and strategic reserves. Supplies for uses other than food could, in most years, exceed one billion bushels without expanding our present base acreage. Freedom for wheat to move in competition with feed grains is governed by price either in the open market or under the influence of government policy.

Recent price changes have tended to establish a base price for wheat about equal to feed grains if protein content is taken into account. This is causing farmers to make decisions on a new basis.

The acre yield of wheat is a major determinant of net returns; hence, ways to increase the yield are of vital importance. Consistent production likewise is important if a feeding program is to be sustained. Productivity is the sum total of soil management, moisture, fertility, timely farm operations, weather, pest control, and responsive varieties. Ways to improve the position of wheat farmers through the alleviation of all of these obstacles without increasing unit costs, is what research is all about in this area.

The average yield per harvested acre has doubled in this century. Another rise of 50% is a reasonable goal to attain by the year 2000. A substantial increase in yield and prices competitive with other grains appear to be the road that must be followed to bring wheat into the feed market on a regular basis.

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