

APPLICATION OF DECISION THEORY
IN DETERMINING WHAT
CROPPING SEQUENCES

by

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I. INTRODUCTION

Wheat yields in the Great Plains are characterized by extreme variation when compared to crop yields in other agricultural regions. This variation has several characteristics. Figure 1 most clearly shows average variation around the mean as measured by coefficient of variation or the relative amount of "risk" at given locations in the Great Plains.

The tendency toward sequences of extreme yields as reflected by coefficient of variability sequence of precipitation is shown in Figure 2. A high coefficient indicates "bunching" of abnormal years of a similar type while a low coefficient indicates a tendency toward alternation.

A third characteristic of crop variability in the Great Plains is the tendency toward geographical concentrations of abnormal yields, as shown for Nebraska in Figure 3, rather than uniform distribution. Similar bunching exists throughout the Great Plains.

In sharp contrast to this physical variation and the historical price variation is the relatively stable survival limit; fixed costs such as taxes, depreciation, land preparation and the need for family living. This survival limit has been estimated at between 25 and 50 percent below the long

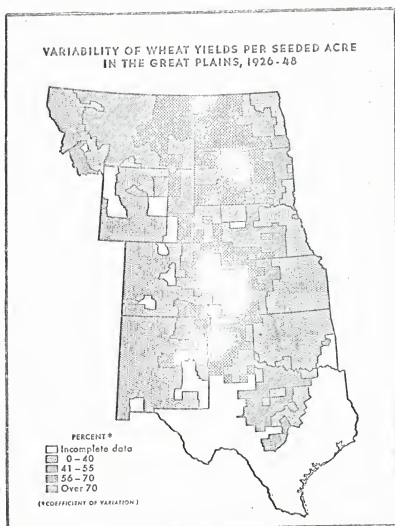
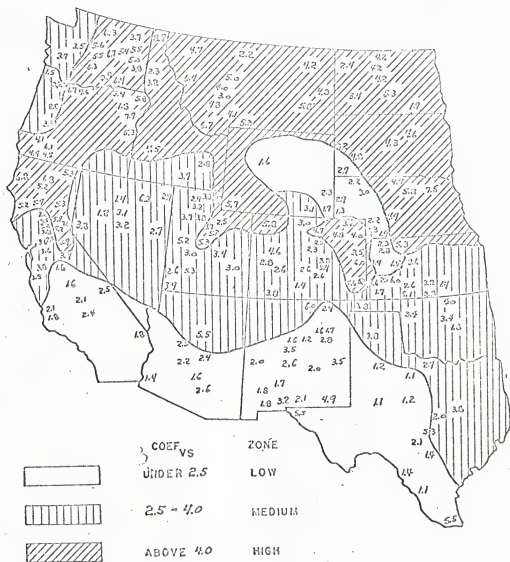


Fig. 1

Source: E. Lloyd Barber and Philip J. Thair, "Institutional Methods of Meeting Weather Uncertainty," Journal of Farm Economics. August 1950, 32:393.



$$\text{COEF}_{vs} = \frac{\text{Precipitation, average deviation from the mean,}}{\text{Precipitation, average cumulative deviation from}} \\ \frac{\text{disregarding sign}}{\text{the mean, disregarding sign.}}$$

Fig. 2.--Coefficient of variability sequence, COEF_{vs} , for average annual precipitation in 17 western states, 1900-39.

Source: Marion Clawson, "Sequence in Variation of Annual Precipitation in the Western United States," Journal of Public Utility Economics, August 1947, 23:261.

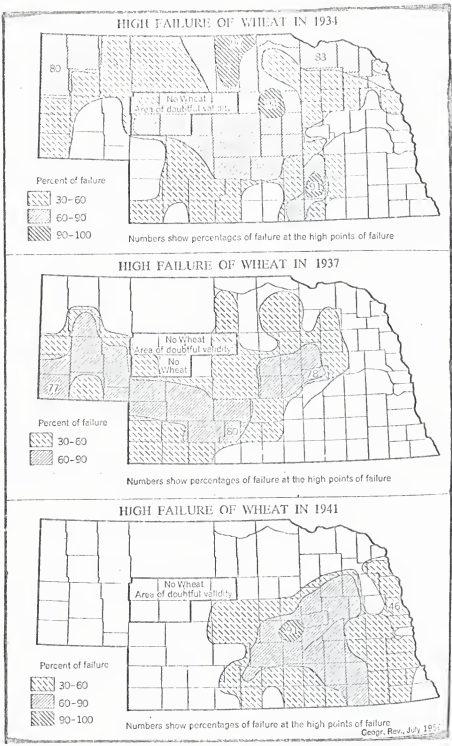


Fig. 3

Source: Leslie Hewes and Arthur C. Schmieding, "Risk in the Central Great Plains: Geographical Patterns of Wheat Failure in Nebraska, 1931-1952," The Geographical Review, July 1956, 46:384.

term average total cost under optimum farm organization.¹

Various methods of maintaining income above the survival limit have been suggested such as crop insurance or diversification, either product or spatial. Credit or outside income may also be used. However, in the present trends of agricultural development, specialization to increase profitability is becoming common and with narrow profit margins, insurance costs may be expensive. This study examines one method a specialized wheat farmer may utilize to reduce variability over a short period, reduce risk of ruin, and increase long term profitability.

It has been shown that a "plan as you go" or flexible cropping system in which the farmer adjusts his cropping program to conditions as they exist and makes no attempts to develop a fixed crop rotation can best accommodate these variable conditions if suitable management techniques are applied.² In flexible farming, a decision process must be used to determine whether or not to attempt to produce a crop, then to determine the best production method. One researcher illustrated the complexity of the problem.³

¹Rainer Schickle, "Farmers Adaptations to Income Uncertainty," Journal of Farm Economics, August 1950, 32: 356-374.

²Elmer A. Starch, "Type of Farming Modifications Needed in the Great Plains," Journal of Farm Economics, February 1939, 21:115.

³Cecil H. Wadleigh, "The Need to Evaluate Weather," Weather and Our Food Supply, p. 7-8.

When a wheat grower in Stanton County, Kansas, plants his grain in the Fall, he can be quite certain of a bumper harvest the following summer:

If there is a good supply of available moisture in the subsoil at the end of the fallow period;

If rains occur in September and October to provide surface moisture essential for germination and seedling growth;

If leaf rust does not appear during the Fall as a result of extensive dewfall or rainy weather with resultant weakening of the young plants;

If Fall weather does not foster an infestation of "green bugs" which seriously weaken the young plants for tolerating winter cold;

If warm weather during the Fall does not abet an infestation of mites that transmit the "mosaic" virus which can wipe out a crop;

If the plants are not winter-killed by sudden cold snaps following warm periods in the absence of snow cover;

If the plants are not blasted by soil blowing as a result of dry surface soil and high wind velocities during early Spring;

If late Spring frosts during anthesis do not bring about sterilization of the flowers;

If there is an adequate amount and distribution of late Spring rains to provide necessary soil moisture to carry the grain through to maturity;

If heavy dews and rainy periods in the Spring do not foster an infection of leaf and stem rust, which damage or even kill the plants;

If hot weather with desiccating winds does not occur during the time of filling resulting in low test weight of grain;

If hot, dry weather does not foster a scourge of voracious grasshoppers to devour the crop;

If convective storms during late spring and early summer do not bring on a barrage of hail to destroy or severely damage the crops;

Finally, if the wheat grower could be liberated from all of the preceding 'ifs' he would 'have it made.'

A formal decision process prior to planting, fertilization, and tillage methods involving all of those inter-related factors obviously is beyond the capabilities of the most skilled decision maker and certainly beyond the scope of this report.

It would be useful for the farmer to have a nomograph¹ which when properly supplied with information pertaining to more important crop inputs at a given decision time such as planting would give an appropriate decision. Such nomographs could be prepared in advance by computers to incorporate data which the individual farmer could neither comprehend nor afford.

Toward developing such a nomograph, this report re-examined the use of one of the important factors, soil moisture at planting, in the light of modern decision theory to illustrate the formal decision process and indicate problems which arise. A basis for developing a moisture decision criteria was developed as was an extensive bibliography.

The procedure followed was to first examine available literature on several cropping systems used for wheat in the Great Plains, continuous, systematic fallow, and flexible farming; second, to examine those portions of decision theory deemed applicable to decision making in flexible farming

¹A graphical representation of mathematical formulae in which a solution may be found graphically.

placing emphasis upon finding an appropriate decision criteria.

While more freedom of management is allowed by inclusion of an alternative crop such as grain sorghum, only wheat and fallow were considered. The analytic framework was not altered by this exclusion, although practical application would necessarily include such alternatives. Price and cost changes were largely ignored as they either change little within the decision period or are more easily allowed for by other means. Restrictions and payments under government agricultural programs were also excluded.

II. REVIEW OF CROPPING SYSTEMS

Important Inputs

Finnell¹ in an early study of wheat production possibilities in the Oklahoma panhandle chose twenty-five variables in wheat production for a correlation study. More complete correlations are available using more year's data, but Finnell's approach to its use is unique in the literature. Four independent variables: average fall soil moisture, average November nitrate content, average raw organic matter content, and average July rainfall, which are known prior to planting were chosen from the list and used to divide production years into groups of above and below average. For each factor, the total number of favorable variables present prior to each of 60 crop years were related to grain yield as shown in Table 1.

It can be seen that this simple model may provide a useful guide to planting or in the formal decision process an experiment-state matrix. This method may not be useful under other circumstances or require weighting of factors as in this case all four had approximately the same absolute standard regression coefficients. However, May wind velocity

¹H. H. Finnell, Estimation of Wheat Production Possibilities in the Panhandle of Oklahoma. Panhandle Agricultural Experiment Station, Bulletin 52, December 1933.

had a higher correlation coefficient than any two other factors combined and at present, weather forecasters can not predict this in advance. A grouping of factors by the meteorological deficit — excess method of Azzi¹ would refine the model.

Table 1. Relationship of four preplanting conditions to wheat yields.²

No. Initial Factors Favorable	No. Crops				Av. Wheat Yield lbs. Per Acre
	Total	Above Ave	Below Ave	Failure	
4	6	6	-	-	1800
3	16	12	4	-	1230
2	20	9	4	7	580
1	17	1	3	13	105
0	1	-	-	1	100

Data on all four factors is available, but collection of probabilities and correlations on all was outside the scope of this report. As soil moisture at planting has been widely studied and is easiest to measure, it was used for this report.

Moisture Regressions

The importance of proper distribution of moisture in the phenologic cycle of plants has long been recognized.

¹G. Azzi, Agricultural Ecology (London: Constable and Co., 1956). A grouping of occurrences of above and below average yields to determine when a meteorological factor was in excess or deficit.

²Finnell, op. cit., Adapted from Table 8, p. 182.

However, in a limited study such as this, crop year average precipitation presents a more manageable independent variable. Wheat yields have been shown by linear regression to be a function of moisture available during the crop seasons.

Equations generally have taken the form:

$$Y = (W-a)b,$$

where: Y = wheat yield, bu/A
 W = water used, inches-soil moisture at seeding plus crop year precipitation
 a = constant for location, generally 8 ± 1
 b = constant for location, ranging from 1.88 at Colby, Kansas¹ to 6.5 at Swift Current, Sask.²

Approximately eight inches are necessary for vegetative growth with an excess used for grain production, efficiency depending upon the location. Mathews and Brown³ observed that

The one striking feature of the calculation (equation) is the degree of exactness with which failure was estimated. Other conditions sometimes prevented the full possibilities of a high water supply from being realized, but apparently other factors were not able to produce a crop when the water supply was deficient.

¹O. R. Mathews and L. A. Brown, "Winter Wheat and Sorghum Production in the Southern Great Plains Under Limited Rainfall," USDA Circular 477, 1938, p. 8.

²J. L. Doughty, et al., Report of Investigations — Soil Research Laboratory, Swift Current, Sask. Experimental Farm Service, Dominion of Canada, 1943, p. 10.

³Mathews and Brown, op. cit., p. 15.

Garden City, Kansas has an average annual precipitation of approximately 17 inches,¹ which in the preceding equation reveals the comparative largeness of the "a" constant for Garden City, — 7.69 inches. Each additional inch of moisture either from storage or precipitation at Garden City increases the yield approximately 2 bushels per acre.

Storage prior to planting under continuous crop at Garden City, is estimated by:²

$$\text{Storage inches} = \frac{(\text{July to Sept precipitation}) - 4.00}{2.25}$$

Average precipitation there results in a 1 inch soil moisture storage with a storage efficiency of 16 percent.

Storage under fallow at Garden City is estimated by:³

$$\text{Storage inches} = \frac{(\text{June to June to Sept precipitation}) - 10.40}{1.67}$$

Average precipitation there results in storage of 7.8 inches with a storage efficiency of 33.6 percent.

Importance of Fallow

While fallow is an inefficient storage method, the added 6.8 inches typically makes possible a 13.6 bushel yield increase over continuous cropping with the same crop

¹I. D. Bark, Weekly Precipitation Amount for Kansas. Kansas Agricultural Experiment Station Technical Bulletin 126, p. 40.

²Mathews and Brown, op. cit., p. 13.

³Ibid., p. 29.

season precipitation. Field studies with various wheat rotations have shown similar results.

Throckmorton and Myers¹ using similar data collected prior to 1939 suggested that from an agronomic standpoint, a wheat, fallow rotation should be used in the western two tiers of Kansas counties a wheat-wheat-fallow rotation in the next two tiers, a wheat-wheat-wheat-fallow rotation in the next two tiers, and no fallow in the rest of the State. They cautioned that:²

The fallow is of sufficient importance in aiding the stabilization of wheat production in the western one-half of the state that a portion of the cultivated land should be in fallow each year. This applies to years of high yield as well as to those of low production and to years of high soil moisture content at seeding time as well as years when the moisture content is low. Some of the greatest responses from fallowing occur in the dry years following years of relatively high rainfall. The practice of seeding every acre of land to wheat during favorable seasons and not reserving some land for fallow is not sound. If, during those years when the soil is well supplied with moisture in the fall, all of the crop land is seeded, an over-production will frequently result the following season and if during that season the rainfall is normal or below normal conditions will not be favorable for seeding in the fall because no land will have been fallowed.

Knight³ in an economic study of frequency of fallow derived similar frequencies for the Eastern fallow region

¹R. I. Throckmorton and H. E. Myers, Summer Fallow in Kansas. Kansas Agricultural Experiment Station Bulletin 293, March 1941.

²Ibid., p. 24.

³Dale A. Knight, Economic Considerations for Selecting the Superior Frequency of Fallow for Wheat in Three Locations in Western Kansas. Kansas Agricultural Experiment Station Technical Bulletin 85, September 1956.

although suggesting more fallow in the west.

Finnell¹ also indicated that the now common practice of summer fallow, while inefficient in moisture storage, does raise the soil moisture level enough to make a profitable crop more often. He indicated, however, that its systematic use is a conservative practice and has not always assured crop success.

If the greatest wastes in production costs are to be materially reduced, drastic limitation of seeding under severely unfavorable conditions must be exercised. This requirement eliminates regular cropping either with or without fallow, and crop rotation, for unless production possibilities are correctly estimated and the indications followed out losses of seed, fuel and labor are bound to continue.²

Flexible Cropping

Experiments at Goodwell, Oklahoma comparing continuous wheat, a wheat-wheat-fallow rotation, and a flexible system were conducted from 1924-33.³ Wheat was planted only when conditions were favorable for average or above average yields with milo used only as a catch crop and considered only an incidental item. Local cash costs only were considered and any labor saved was considered lost.

Results are summarized in Table 2.

¹H. H. Finnell, Adjustment Problems in Wheat Production. Panhandle Agriculture Experiment Station Bulletin 54, June 1934.

²Ibid., p. 5.

³Ibid.

Table 2. Ten year averages, 1924-33, grain production of three wheat systems at Goodwell, Oklahoma.¹

	Comparative Percentages Taking Continuous Culture as 100										
	Yield lbs. Grain Per Acre	Lbs. Wheat	Lbs. Milo	Wheat	All Crops	Fallow	Wheat Production	Operating Cost Per Wheat	Wheat Labor Income	Total Labor Income	Relative Efficiency of Wheat Production
	Total 10 Year Grain Production Per Acre										
Continuous Wheat	544.4	5444	0	100	100	0	100	100	100	100	100
Wheat-Wheat-Fallow	704.1	4694	0	66	66	33	86	78	96	96	110
Flexible	1057.7	4231	5523	40	80	20	77	47	101	130	163

It can be seen that the flexible system had the lowest operating cost and highest efficiency even though total wheat production decreased. The "catch" milo crop made total grain production highest under the flexible system. Examination of yearly records shows that failures were avoided and that only

¹Ibid., p. 7.

one bumper crop was missed, that due to extremely unfavorable fall conditions which limited planting. Finnell admitted that his decisions were based on meager information and recognized that "much basic information is needed as considerable study and experience by those attempting such a system, in order to make it a workable plan."¹

Crop Abandonment

Hallsted and Mathews in an approach similar to that of Finnell, suggesting abandonment or refraining from planting when conditions are unfavorable in order to prevent incurring dollar and moisture costs.² Using depth of wet soil at planting as a criteria they found the following:

Table 3. Probabilities of obtaining specified yields of wheat when the soil was dry or wet to designated depths at seeding time, as determined by results Hays, Colby, and Garden City.

Depth to which Soil was wet	Failure 4 bus. or less	10 bus. or more	20 bus. or more	30 bus. or more
Dry	71%	18%	0%	0%
1 Foot	34%	43%	19%	0%
2 Feet	15%	62%	29%	9%
3 Feet or more	10%	84%	70%	23%

This table based on 186 crop year situations provides

¹Ibid., p. 8.

²A. L. Hallsted and O. R. Mathews, Soil Moisture and Winter Wheat with Suggestions on Abandonment, Kansas Agriculture Experiment Station Bulletin 273.

a useful, limited experiment-state matrix¹ for decision making.

The basic philosophy involved in this decision situation was summarized by Hallsted and Mathews:²

The fact that wheat on Fallow at Garden City and Colby produced yields nearly double those on methods of preparation where wheat followed wheat, does not mean that all the wheat should be grown on an alternate fallow and crop basis. The desirability of including some fallow in the farming system as an insurance against failure appears to be self-evident. But in many years a crop may be obtained on wheat land with very little expense.

It would seem desirable to limit wheat acreage in years when wheat must be planted in a dry soil. Seeding can usually be delayed until well in October without materially decreasing yields, and, except where acreages are very large, it is better to wait for rain than to plant in hopes of rain. Land not planted to wheat in the fall may be planted to other crops the next spring, or it may be fallowed. If the land is fallowed, the grower can feel certain that on the average more wheat will be produced by the one crop planted on fallow than would have been produced by the crop planted in dry soil and a crop the following year.

If the soil is wet to a depth great enough to give wheat a start, but not enough to provide a reserve supply of water, wheat can be planted with the purpose of harvesting the crop if conditions are favorable after planting and of abandoning it if they are not. Wheat planted in a soil wet to a depth of only a few inches is dependent upon conditions after seeding. Average rainfall after seeding has almost never produced a good crop, but above normal rainfall has. Wheat planted under such conditions should be watched with the full knowledge that a low rainfall in the months following seeding is almost certain to result in failure. The absence of above normal conditions is an indication that abandonment may be desirable. Conditions much below

¹A formulation of the probabilistic relationship between some known variable and that which it predicts.

²Hallsted and Mathews, op. cit., p. 44-45.

normal are an almost positive assurance that abandonment will usually be best.

The important matter is to recognize the need for abandonment when it arrives and to take advantage of it. Land, where the wheat warrants abandonment, can be plowed or listed early in May with the assurance that any small yield that may be lost will be more than compensated for in the following crop, if the land is kept clean during the summer. Wheat land harvested in good years and abandoned in poor years gives the opportunity of reaping a crop when conditions are right and of fallowing when they are not.

Early abandonment when conditions warrant need not be looked upon as the loss of a crop. Rather it may be looked upon as a method of cultivation that helps to insure a crop the next year.

In some years wheat badly damaged by drought makes an astonishing recovery if abundant rains fall. However, this recovery is frequently more apparent than real. The growth that takes place on drought -- injured grain is generally much later than normal, and ripening is delayed until the hottest part of summer. The result frequently is a low yield of shriveled grain. The moisture that might have been saved for producing a crop the next year is used up in producing a crop of doubtful value. There is a possibility that prolonged cool weather may enable such a crop to fill properly, but this seldom occurs. On the average, it is better to save the moisture for the next crop than to allow it to be used by the drought -- injured crop. Wise abandonment permits a wheat grower to take advantage of fallow in many years without too large a percentage of his land being in fallow every year.

Formal decision process was investigated to utilize this philosophy.

III. APPLICABLE DECISION PROCESS

Decisions are made under three general conditions: certainty, risk and uncertainty.

In general, if an a priori probability distribution over the states of nature exists, or is assumed as meaningful by the decision maker, then the problem can be transformed into the domain of decision making under risk.¹

Amount of crop year or annual precipitation as used in this study is such a situation.

Uncertainty then includes situations in which no probability distribution is deemed meaningful and, less formally, those situations which occur infrequently, but are catastrophic in nature. The frequency of various precipitation distributions within a crop year is probably not known well enough to classify as a risk situation and is here treated as uncertainty.

Decision Under Risk

The decision process under risk takes place in three steps once the problem has been identified: the inputs and production functions must be identified, frequency distributions must be found for independent variables and a decision criteria must be developed and applied.

¹Robert D. Luce and Howard Raiffa, Games and Decisions, (New York: John Wiley, 1957), p. 277.

Raiffa and Schlaifer¹ listed formally the data needed to make a decision: there must be an exhaustive listing of the possible states of the world, $\theta = \{\theta\}$ ², which determine the consequences of adopting an act; a family of experiments, $E = \{e\}$, which the decision maker utilizes to find an outcome z in order to predict the true state of the world θ ; a list of possible acts, $A = \{a\}$, which the decision maker may choose; an utility evaluation, u , which the decision maker assigns to performing an e , observing z , taking a and accepting the consequences θ . Included in u is the cost of e as well as the consequences of a . A probability assessment, $P_{e,z}$, which gives the probability that any outcome of e , z , is actually the real θ , as shown in the possibility cartesian product space $\theta \times Z$. The utility function is finally used to develop a family of decision rules, $D = \{d\}$ which assign an act, a , to each possible outcome, z , of the chosen experiment, e .

The general decision problem then is "given E, Z, A, θ, U , and $P_{e,z}$, how should the decision maker choose an e and then, having observed z , choose an a in such a way to maximize his expected utility?"³

As complex a decision process as deemed profitable

¹Howard Raiffa and Robert Schlaifer, Applied Statistical Decision Theory (Boston: Harvard University, 1961), p. 3-4.

² $\theta = \{\theta\}$ is a mathematical notation. The capital θ referring to all possible states; this being equal to $\{\theta\}$ which stands for $\theta_1 + \theta_2 + \theta_3 \dots \theta_n$, the summation of individual states.

³Raiffa and Schlaifer, op. cit., p. 6.

might be developed. This would entail collecting information about moisture — yield functions, soil moisture at seeding — total moisture functions, phenological moisture requirements, moisture distributions and complex interrelationships. To increase the accuracy of such a moisture based decision process while ignoring such other factors mentioned by Finnell as soil fertility and other weather variables is questionable, especially in view of the high correlation of temperature at heading, twice that of any other factor in most studies.

In this report, measurement of soil moisture at planting was chosen as the experiment, e , with the observed outcome, z , being the amount of moisture available. A simple soil moisture — yield matrix such as found in Table 3 could be used as the $\Theta \times Z$ product space. Such a matrix may be easily developed for any region where soil moisture and yield date is available. A promising improvement would be to use the Palmer index¹ as the moisture variable as temperature and precipitation records which form the basis for the index are more readily available than soil moisture data. The index also may be used to indicate the presence and severity of abnormal weather to aid in resource planning. Such data are available and are adaptable to computer data processing.

¹Wayne C. Palmer, Meteorological Drought. United States Weather Bureau Research Paper No. 45. (Washington: Government Printing Office, 1965).

Decision Criteria of the Individual

Selection of an appropriate decision rule by using an appropriate decision criteria in conjunction with the $\theta \times Z$ product space completes the process.

Individual utility. Study of decision criteria and utilities associated with them are often based upon the goals and values of those making the decisions in question. But as Baumol¹ stated:

There is no simple method for determining the goals of the firm (or of its executives). One thing, however is clear. Very often the last person to ask about an individual's motivation is the person himself (as the psychoanalysts have so clearly shown).

The major point, both in economic analysis and in operations-research investigation of business problems, is that the nature of the firm's objectives cannot be assumed in advance. It is important to determine the nature of the firm's objectives before proceeding to the formal model-building and the computations based on it.

Thair,² in discussing farmer's objectives noted that it is difficult to measure such goals as happiness, the good life or independence, and that we can not now measure these goals meaningfully. The implicit conflict between personal values and demands of the environment on the firm makes selection of decision criteria complex. However, to find this point for given conditions it was necessary to examine both firm and personality characteristics.

¹William J. Baumol, Economic Theory and Operations Analysis (Englewood Cliffs, N. J.: Prentice-Hall, 1961) pp. 192-193.

²Philip J. Thair, Meeting the Impact of Crop-Yield Risks in Great Plains Farming. North Dakota Agricultural Experiment Station Bulletin 392, June 1954, p. 8.

While economic factors appear paramount,

We assume nevertheless that no matter how intricate these considerations are, the decision maker is psychologically able to act and therefore can not only rank complex stimuli of this sort but assign to them utility numbers which reflect his preferences among lotteries having such stimuli as prices.¹

The manager may face ridicule by neighbors or sanction by landowners at not planting a crop, if later conditions allow the rare profitable crop. Each manager has some characteristic ability to face ridicule at a "wrong" decision which may be related to a balance of probability of missing a profitable crop and other factors. This percentage could be applied to an appropriate curve to determine whether with existing conditions, chance for ridicule is excessive.

Each individual or firm has a utility function based upon goals described by Schickele:

- (a) To assure the farmer's survival in case of heavy risk losses (whenever they might hit), and
 - (b) to maximize income over time subject to (a).
- They are not coordinate, the survival end has priority over the maximization end.²

A common factor, stability of income, complicates the relationship. Only a balance between the two is relevant if the firm or individual wishes to remain in business. Horton and Barber³ implied a skewed nature of this balance by questioning whether ". . . the farm business that takes measures to

¹Raiffa and Schlaifer, op. cit., p. 22.

²Schickele, op. cit., p. 362.

³Donald C. Horton and E. Lloyd Barber, "The Problem of Farm Business Survival in areas of Highly Variable Rain-Fall," Journal of Farm Economics, November 1949, 31:944.

safeguard itself against failure earn enough in the long run to cover the added costs of this production."

Theoretical decision criteria provided a start to find a balance. As described by Milnor,¹ the Laplace criteria or principle of insufficient reason, that under uncertainty you must assume all outcomes as equally probable is neither applicable or useful. The remainder provide the extremes possible under risk. The maximax criterion requires choosing the act which gives the highest return under one of the possible states. This is similar to planting all land available to wheat in an arid region in hope of the occasional "bumper" crop. Such an individual would have a high utility for gain with low disutility for loss.

The maximin criterion requires selecting a strategy which has the best worst state. The decision maker adopts a strategy which offers the largest minimum return. Such an individual would have a high disutility for loss and relative low utility for high immediate returns, and in our case would probably choose a regular fallow rotation.

A mixture of these extremes may be used to moderate or modify their properties. The Hurwicz α criterion (pessimism -- optimism index) is one such mixture.² α is an index of the balance between utility of gain and disutility of loss having the properties: $0 \leq \alpha \leq 1$. The α index of

¹ John Milnor, Games Against Nature, p. 49-50.

² Luce and Raiffa, op. cit., p. 282.

an act a_i is $a_i = \alpha m_i + (1 - \alpha)M_i$, where m_i is the smallest outcome of $a_i e_i$ and M_i is the largest outcome of $a_i e_i$. The preferable act has the largest α index. Note that when $\alpha = 1$ the Hurwicz criterion becomes the maximin criterion and when $\alpha = 0$ it becomes the maximax criterion.

α may be found by setting up a simple situation such as:

a_1	θ_1	θ_2	
	0	1	where α indices of a_1 and
a_2	X	X	a_2 are $1 - \alpha$ and x respectively.

X is then chosen so that a_1 and a_2 are indifferent. This may then be used in more complex situations.

Other mixed strategies are available. The much studied minimax strategy, developed by Morgenstern and von Neuman¹ has been applied to agricultural problems,² but it implies a rational opponent intentionally attempting to minimize his opponents gain and is conservative against an impersonal factor such as nature, others would give more profit.

Using these types of data to develop a decision rule seems at this time to be relatively inefficient when compared to environmental data and accuracy of processing available. Finding individual utilities is costly, often inaccurate,

¹John von Neuman and Oskar Morgenstern, Theory of Games and Economic Behavior (Princeton: Princeton University Press, 1947).

²James D. McQuigg and John P. Dell, "Economic Analyses Involving Random Weather Inputs," Journal of Farm Economics, November 1961, 43:909-920.

and may not reflect the utility of the same individual at a slightly later time. However as Baumol¹ indicated the problem of finding utilities is often avoidable in many practical cases.

For if there are some problems for which the optimum decision will be the same, no matter which of a number of objectives the firm happens to adopt, it is legitimate to avoid altogether the difficult job of determining company goals before undertaking an analysis.

A Decision Criteria of the Firm

Utility curves can be developed for a firm using the concept of the survival limit in relation to the firm's reserves as a measure of the need to insure short term survival. Such a study would involve balancing probability concepts such as expected duration of a game, with the firms planning horizon as in the classical ruin problem.²

The basic ruin problem involves an individual who is gambling against an infinitely rich adversary who is always willing to play. The individual enters the game with a stake, z , wishing to play until he has increased his stake to a or becomes ruined, the expected duration of the game being D_z games. At the end of each play, his stake increases or decreases one unit with probability p or q , respectively.

Probability of ruin, q_z , is found by:³

¹Baumol, op. cit., p. 193.

²William Feller, An Introduction to Probability Theory and Its Applications, p. 313-317.

³Ibid., p. 315.

$$q_z = \frac{(q/p)^a - (q/p)^z}{(q/p)^a - 1} \quad p \neq q$$

$$q_z = 1 - \frac{z}{a} \quad p = q$$

Expected duration of the game, D_z , is found by:¹

$$D_z = \frac{z}{q-p} - \frac{a}{q-p} \cdot \frac{1 - (q/p)^z}{1 - (q/p)^a} \quad p \neq q$$

$$D_z = z(a - z) \quad p = q$$

Expected duration of the game, $E(G)$, is found by:²

$$E(G) = a(1 - q_z) - z$$

From Figure 4 the effect of changing the probability of annual loss can be seen on the probability of ruin for different amounts of capital, z , when the hoped end, a , is 25. For decreasing amounts of capital, the risk increases as was shown by Kalecki³ in the principle of increasing risk.

Figure 5 is the same as Figure 4 except that the value

¹Ibid., p. 316.

²Ibid., p. 315.

³M. Kalecki, Essays on the Theory of Fluctuations (London: Allen and Unwin, 1939) p. 339.

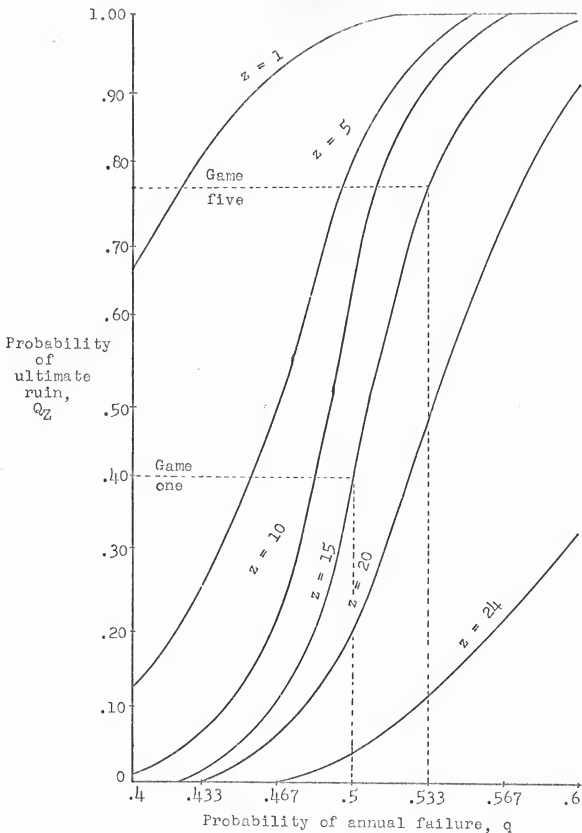


Fig. 4.--Probability of ultimate ruin, Q_Z , given probability of annual failure, q , and starting units of capital, Z . Annual gain or loss is one unit. Game continues until capital reaches 25 or 0.

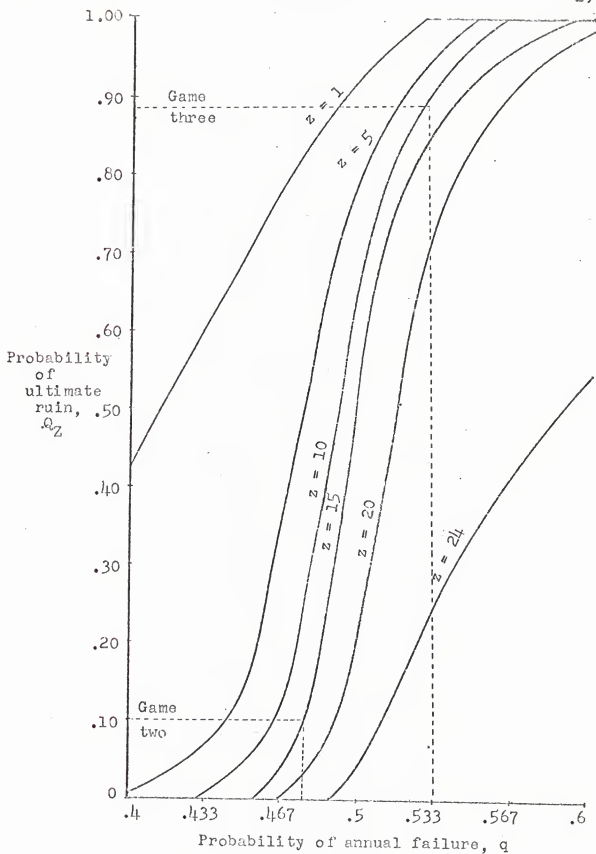


Fig. 5.--Probability of ultimate ruin, Q_z , given probability of annual failure, q , and starting units of capital, Z . Annual gain or loss is one-half unit. Game continues until capital reaches 25 or 0.

of each game has been reduced to 0.5 unit. Comparison will reveal that:

If the stakes are doubled while the initial capitals remain unchanged, the probability of ruin decreases for the player whose probability of success is $p < \frac{1}{2}$ and increases for the adversary (for whom the game is advantageous).

In a game with constant stakes the gambler therefore minimizes the probability of ruin by selecting the stake as large as consistent with his goal of gaining an amount fixed in advance. The empirical validity of this conclusion has been challenged, usually by people who contended that every 'unfair' bet is unreasonable. If this were to be taken seriously, it would mean the end of all insurance business, for the careful driver who insures against liability obviously plays a game that is technically 'unfair'. Actually, there exists no theorem in probability to discourage such a driver from taking insurance.¹

The expected duration of the game also varies markedly with size of capital and yearly probability of success as does the expected gain.

This material may be used to prepare a nomograph to be used to show either the maximum amount of annual risk which can be accepted given a disutility of risk of ruin and the expected length of the game or the value of increasing the probability of success upon the firm's survival.

In application to this report, probability of success, p , or failure, q , is related to the profitability of the expected crop which, considered from an income viewpoint, is related to yield. The classical game would need to be modified to reflect the general inequality of profit or loss

¹Feller, op. cit., pp. 315-316.

of a single crop. This profitability-probability transformation is outside the realm of this paper as is utilizing data available.

However, some of the value of such an analysis can be shown by simple hypothetical examples within the framework of the classical game. The examples may not reflect actual situations because of deviations from the classical formulation.

Assume that expected profit and loss are exactly numerically equal. In order to approximate the classical game, we state that living and cropping expenditures equal average income so that if there is a crop failure, there is a loss of some amount and if gross income is twice these expenses, a gain of the same amount. The annual probability of loss is some discrete value found by measuring soil moisture at planting. Assume a goal of farming until the estate reaches 25 units of capital or becomes bankrupt. By a different approach using the expected duration of the game, some planning horizon could be specified. Knowing these data and available capital, an analysis of the farm "game" can be made.

Game 1. Assume 15 units of capital and an annual probability of failure for continuous wheat of 0.5, if continuous crop requires a total stake of one unit, from Figure 4 the probability of ultimate ruin is 0.4. Should the decision maker farm? It has been shown that it is difficult to measure a utility such as disutility of loss. If this information is available, a determination could be made. If not,

only a comparison of farming with other occupations or enterprises is possible.

The expected gain of one game is given by the formula:

$$\begin{aligned} \text{Expected gain} = & (\text{probability of gain})(\text{gain}) \\ & - (\text{probability of loss})(\text{loss}). \end{aligned}$$

In this game expected gain is zero (plus the already subtracted living expense). By the formula for ultimate expected gain, it also is zero.

Game 2. An alternative enterprise is a fallow-wheat rotation. From some hypothetical experiment-state matrix it is known that with average conditions, the probability of loss falls to 0.480. If fallow decreases the stake per year to 0.5 unit, the probability of ruin would be 0.10 from Figure 5. Expected gain becomes 0.066 unit. The ultimate expected gain becomes 12.5 units. Clearly under these conditions a fallow rotation is superior.

A different analysis must be used to study a flexible cropping system. What is needed is a criteria by which the probability at which a successful continuous wheat crop and of a successful fallow crop are found to be indifferent in regard to ultimate ruin.

Game 3. Assume that at planting time it is determined that soil moisture is at a level that continuous wheat which now requires 0.5 unit from Figure 5, will fail with a probability of 0.533, probability of ultimate ruin is 0.88, the expected ultimate loss is 12.25 and the annual loss is 0.066.

Game 4. For fallow:

Expected annual gain = (probability of gain)(gain)
 - (probability of loss)(loss) - expense incurred
 in fallow year.

Assume an added expense of 0.2 units for the fallow period and no other change from Game 3. The above equation becomes for fallow to be indifferent:

$$0.066 = (1 - q)(0.5) - (q)(0.5) - 0.2$$

$$q = 0.366$$

Thus if fallow will reduce probability of failure below 0.366, it should be used. No analysis of probability of ultimate ruin can be made under the formulation presented as losses not equal gains.

Game 5. Under the conditions of Game 3, assume that addition of fertilizer doubles the possible loss and the possible gain. The probable annual loss becomes twice that of Game 3 or 0.132. From Figure 4, the ultimate probability of ruin becomes 0.774. Thus doubling the stake decreased the probability of ruin.

These examples illustrate the usefulness and departures from normally believed situations which the classical ruin problem reveal. It is virtually meaningless to describe other situations because slight changes in formulation result in marked changes in outcome when exponents are involved as is shown by differences between Figures 4 and 5.

It does suggest another approach to the problem as an approximation.

Consider the farmer facing a dry year with no reserves, no fallow, and only sufficient capital to continuous crop. The decision maker has no choices other than to crop or quit. Not until sufficient capital is available to fallow some acreage after meeting the survival limit does a decision become possible. Then he must determine how much continuous crop to plant so that the survival limit will be reached that year with a predetermined probability. In a dry year, possibly all. Again there is little room for a decision. However, these are unusual circumstances usually occurring with beginning farmers or after prolonged crop failure and in the practical case introduction of another strategy such as crop insurance is more promising.

The more usual case of sufficient reserves allows more freedom for decision. A wet year with sufficient capital to allow either continuous crop or fallow or a mixture of the two increases the decision possibility. Fallow in this case has been advocated as adding stability to the next year, but if more income can be produced by continuous crop, it would seem that reserves other than soil moisture such a credit, crop insurance, or savings would be more profitable and these reserves may be used to aid survival and stability. Sufficient reserves allow fallow cropping during dry years until the above analysis holds.

Thus in the normal situation, it is useful to assume

that the firm's best decision criteria for variable cropping is to maximize income over a short period and assume that survival and stability are either little affected by fallow except in that its use may increase profitability and thus reserves, or are more easily achieved by other practices.

A First Approximation: Maximum Profitability

There are three possible decision situations and two possible decisions in this framework: unfavorable conditions with a decision to fallow; favorable conditions with a decision to attempt to crop; and favorable conditions such that even though a profitable crop could be possible, regardless of antecedent conditions, fallow would be more profitable.

Considering the first two cases only, the apparent problem is determining the break-even point on continuous crop. Appropriate costs could be found using the cost data from published sources and knowledge of typical farming practices, from farm management records, or by the method of Knight,¹ using established costs and adjusting them for annual changes. Expected income could be found from the average yield at the measured soil moisture level and the expected price. Comparison would indicate the profitability of continuous crop and desirability of cropping or fallow. For example, a nomograph such as Figure 6 can be developed to graphically show profitability and expected variability.

Such an analysis has the advantage of simplicity.

¹Knight, loc. cit.

However, the implicit assumption of constant utility in the income analysis may make rare high yields disproportionate. If all land were cropped in any one year, excess tillage and harvesting requirements could result followed by complete fallow and resulting underemployment if fallow were indicated the next. Costs could be increased. Such conditions would not occur often and for a large farm, some areas would be in fallow, and some in continuous crop in any one year. The most serious fault is exclusion of the third decision situation.

If there are years and costs such that, even though continuous crop should be favorable, fallow should be more favorable with the same post-planting conditions, the above analysis is conservative. Here more assumptions are necessary, the calculations more complex, and management more complex.

If it is assumed that weather periods are independent, that all moisture and fertility are used in crop production with no residual effects, and that a decision to fallow or crop has no disrupting effect upon the production operations, the decision process is simplified. Some analysis must be made of expected conditions through the next cropping year. Then with as detailed methods as desired, the expected profitability of fallowing for a larger crop the next year may be determined. Comparison of this with the probability of the expected profitability of a continuous crop plus some portion of profit of the succeeding crop would indicate

whether to crop or fallow.

These computations could be worked in detail and presented in nomograph, similar to Figure 5, or other readily utilizable form for use of farmers in various areas. Expansion of this procedure to include other crops and inputs could increase the accuracy of decision making without undue cost to the farmer.

Figure 6 is the basic nomogram for computing expected profit of a wheat crop when water used in the growing season, price and production cost are known. It is based upon the data for Colby, Kansas previously presented.

The left portion is that with which this report is concerned, the moisture-yield relationship. In Figure 6 water use is related to yield by some multiplier on the confidence scale. After the research outlined in this report has been completed a scale labeled water available at seeding would be used. The confidence scale would be calibrated with a probability scale so that as shown by the upper and lower line would describe the area of yields within some statistical confidence index.

In use, a line is drawn between the water used scale and the center of the confidence scale. The point of intersection with the estimated yield line is the estimated yield. A line drawn between this point and the price multiplier scale to the estimated income scale gives the estimated income. A line connected to the production cost line gives the estimated profit given the previous parameters. Similar

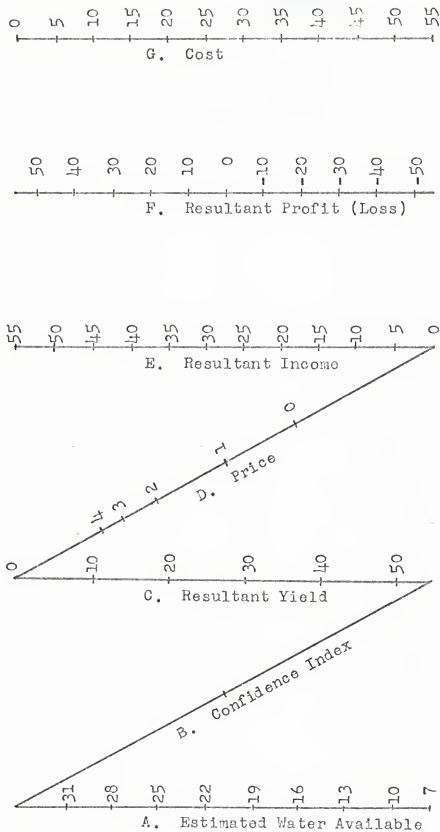


Fig. 6.--Nomograph for computing estimated profit or loss for wheat at Colby, Kansas given: quantity of water available for plant use, confidence index or statistical probability scale, wheat price, and cost of production. Order of line construction is as follows: A through B to C, C through D to E, and E and G through F.

lines constructed as various points on the confidence scale would define the estimated profit range.

The nomogram presents no new information, it is merely a convenient method of graphically computing income. Different nomograms for various enterprises allow quick comparison between the enterprises.

IV. CONCLUSIONS

In order to fully realize the advantage of using modern decision theory to analyze a flexible cropping system, much theoretical work must be done to develop a realistic decision criteria having general applicability. The author believes that what must be sought is a reasonable balance between the need for survival and the need for profit. As active strategies such as variable farming may cause them to be complementary while passive strategies such as insurance may cause them to be competitive, the actual utilities of each need not be computed. One approach to seeking this balance is through the classical ruin problem. When modified to allow for differences in possible gains and losses and the statistical distributions of magnitude of each, it would show the survival value of decreasing risk or the related value of increasing profitability and probability of a profit upon expected survival of the firm. Computation for various ratios of total yearly costs to the assets of the firm would present a useful graphic interpretation of the principle of increasing risk. Upon analyzing the ruin problem, the author felt that in the normal farm situation, an approximation based upon maximum profitability is useful and an outline of that method was given.

Given a suitable decision criteria and available crop-environment data, modern computational methods could develop a decision rule for any area of the plains. This data could be presented in a nomographic form so that a farmer knowing his soil moisture level and such other environmental data included in the nomograph such as soil nitrate level and factors pertaining to his farm business; mainly fixed and variable costs of fallow and cropping, fixed and variable assets, and an expected wheat price may easily decide whether to fallow or crop and if so which crop.

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APPLICATION OF DECISION THEORY
IN DETERMINING WHEAT
CROPPING SEQUENCES

by

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B. Sc. Agr., Kansas State University, 1961

AN ABSTRACT OF A MASTER'S REPORT

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Department of Economics

KANSAS STATE UNIVERSITY
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Crop yields in the Great Plains are characterized by extreme variability, both between years and between locations within a year. This variability is characterized by an apparent aperiodicity which complicates management adjustments. Such passive measures as insurance and crop or cash reserves have been utilized as have active measures such as spatial or product diversification, summer fallow, and outside income as well as a system of variable cropping based upon environmental conditions. The latter was the basis of this report.

There is a need for a simplified decision rule to aid farmers in adjusting their cropping systems to best utilize environmental conditions to maximize profit and security. Modern computational methods enable researchers to process the vast amount of information available relating crop yields to weather variables and probabilities associated with them. These experiment-state matrices are available. Not available are applicable, related utilities or decision criteria which allow computation of a decision rule. Several decision criteria were presented which may be useful if the disutility of risk of an individual is known.

It was suggested that a general decision criteria based upon the firm may be developed using the classical ruin problem as a base. Such a criteria would show, based upon the relationship between the firm's assets and the expected gain or loss, the value of decreasing risk in a one crop period, either continuous or fallow. Not developed was the method

of altering the classical ruin problem to conditions in which expected gain and loss are not equal and a method of converting the effect of increased profitability on probability of loss.

The usefulness of a criterion of maximization of income over a short period as a first approximation to the ruin problem was discussed along with an example of a nomograph for computing profitability of a wheat crop.

An extensive bibliography was developed to present sources of information pertaining to the management problem of risk and uncertainty in the plains, crop-weather information, and basic statistical sources useful in developing the decision rule.