WORLD METEOROLOGICAL ORGANIZATION

TECHNICAL NOTE No. 164

THE ECONOMIC VALUE OF AGROMETEOROLOGICAL INFORMATION AND ADVICE

by
M. H. Omar
CAgM rapporteur

WMO - No. 526

Secretariat of the World Meteorological Organization - Geneva - Switzerland

WMO

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- To facilitate world-wide co-operation in the establishment of networks of stations for making meteorological observations as well as hydrological and other physical observations related to meteorology, and to promote the establishment and maintenance of centres charged with the provision of meteorological and related services;
- To promote the establishment and maintenance of systems for the rapid exchange of meteorological information;
- To promote standardization of meteorological and related observations and to ensure the uniform publication of observations and statistics;
- To further the application of meteorology to aviation, shipping, water problems, agriculture and other human activities;
- To promote activities in operational hydrology and to further close co-operation between Meteorological and Hydrological Services;
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FOREWORD

Early in the 1970's, world food reserves, already eroded by a rapidly increasing population, were further depleted as a result of low food production caused by unfavourable weather in many key food-producing areas. The stress and hunger felt in many parts of the world underlined the dependence of food supplies on weather conditions and pointed to the need to re-appraise the role of agrometeorology in agricultural planning and production.

The Fifth Session of the Commission for Agricultural Meteorology (1971) recognized that an agricultural community more informed on ways and means of using weather and climate information would be in a better position to avoid the harmful effects of adverse weather, thereby increasing food production. With a view to illustrating the economic value of agrometeorological information and advice as an aid to food production, the Commission appointed Dr. M. H. Omar (Egypt) to review current knowledge on the subject. He has accordingly prepared a report which constitutes the present Technical Note.

It gives me great pleasure to extend to Dr. Omar the appreciation of the World Meteorological Organization for preparing this Technical Note. I feel confident it will stimulate greater application of agrometeorological information to agriculture.

Geneva,
February 1979

D. A. Davies
Secretary-General

SUMMARY

Agrometeorological information and advice can help significantly to increase quantity and quality of food, wood and fibre. Better application of agrometeorological resources can not only lead to increased production, but can appreciably reduce loss and damage to agricultural products during transportation and storage. This report deals with ways and means of realizing these objectives and introduces the economic value of applied agrometeorology. With an understanding of relative values, we can give more realistic priority to agrometeorological resources.

Chapter 2 gives examples of meteorological information, how it is used in agricultural management, and its economic value. Much of the material concerns decision-making in weather/agriculture relations. Studies weigh the use of weather forecasts against climatological probabilities.

Chapter 3 provides detailed case studies using climatological data, real-time observations and weather forecasts. Cases concern fallow versus continuous cropping of spring wheat, dry-land farming, irrigation in sub-humid areas, in-storage grain-drying equipment and environment modification of dairy-cow housing. Other cases show the economic value of weather forecasts to cotton planting, haying, raisin drying, pea harvesting and forest logging. These studies demonstrate that use of meteorological information in agricultural planning and operations can be of considerable value and that economic gains are often much larger than cost. Also, forecasts need not be perfect to be useful.

Chapter 4 reviews brief case studies on many topics, including suitable dates for farm operations, land use, supplementary irrigation, protection from frost, hail suppression, plant and animal diseases, animal housing and forest fire protection. Several studies indicate costs of agrometeorological information and protective measures and list cost/benefit ratios.

In Chapter 5, Dr. Omar cites examples of benefits and costs of agrometeorological services in various countries. Although these are often difficult to evaluate in purely financial terms, it is important to attempt analysis. If sensible and conservative terms are used, even rather large errors in benefit/cost values can be tolerated. Studies suggest that meteorological information of comparable cost produces higher economic benefit when applied to agriculture than when applied to other sectors of the economy.

Chapter 6 presents case studies in developing countries. In developed countries agriculture has already assumed its main lines of operation, so that agrometeorology is often a matter of protection from and fight against weather calamities. Much of the large sum attributed to economic value of agrometeorological information and advice in developed countries is, in fact, due to losses which have been avoided. The economic role of meteorology in a developing country is primarily to contribute to development by improving the return from agriculture; thus economic benefits are positive and not merely losses avoided. Benefits can actually represent an important percentage of the national income.

Chapter 7 discusses potential gains to be realized if agrometeorological information were improved. Case studies point out that, even within the present state of meteorological knowledge, significant gains could be realized. Application of information from space satellites and new data-processing technology are among the means of achieving such improvement.

Concluding the Technical Note, Dr. Omar cautions about assessing the benefits to agriculture attributed to present and improved agrometeorological information and advice. For example, increased production for a particular community cannot be automatically translated into increased value. Complex economics is at work in factors such as supply, demand and price. Nevertheless, wiser land use is a reasonable outcome; enhancement of the land rather than degradation of it. The better we understand interrelationships of weather, soils, and plant and animal life, and exploit our knowledge of these relationships, says Dr. Omar, the better we can manage our resources even with - especially with - capricious weather.

RÉSUMÉ

Renseignements et avis agrométéorologiques peuvent beaucoup contribuer à accroître la quantité et à améliorer la qualité des denrées alimentaires, des bois et des fibres. Grâce à une meilleure utilisation des connaissances agrométéorologiques il devrait en effet être possible, non seulement d'accroître la production, mais aussi de réduire de façon appréciable les pertes et les dégâts qui peuvent se produire durant le transport et l'entreposage des produits agricoles. Le présent rapport traite des moyens à employer pour atteindre ces objectifs et expose le concept de la valeur économique des applications de la météorologie agricole. Une meilleure connaissance des mérites respectifs des diverses applications devrait permettre d'allouer de façon plus réaliste des priorités aux ressources agrométéorologiques.

Le chapitre 2 cite quelques exemples de renseignements météorologiques, décrit la manière dont ils doivent être utilisés en matière de gestion agricole et indique leur valeur économique. Une grande partie de ce chapitre traite de la façon dont il convient de prendre des décisions dans le domaine agricole en tenant compte des conditions météorologiques. Ce chapitre procède également à une étude comparée de l'utilité des prévisions météorologiques et de celle des probabilités climatologiques.

Le chapitre 3 contient une description détaillée d'études de cas faites au moyen de données climatologiques, d'observations d'utilisation immédiate et de prévisions météorologiques. Ces études de cas portent sur les sujets suivants : jachère par opposition à culture continue du blé de printemps, aridoculture, irrigation dans les zones subhumides, équipement de séchage des grains pendant l'entreposage et modification de l'environnement pour l'élevage des vaches laitières. Les autres cas étudiés ont trait à la valeur économique des prévisions météorologiques pour la plantation du coton, la fenaison, le séchage du raisin, la récolte des pois et l'exploitation des forêts. Ces études démontrent que l'emploi de renseignements météorologiques pour la planification et l'exécution des opérations agricoles peut se révéler très utile et se traduire par des gains souvent bien supérieurs aux coûts, d'autant plus qu'il n'est pas nécessaire que les prévisions soient parfaites pour être utilisables.

Le chapitre 4 expose brièvement des études de cas portant sur de nombreux sujets tels que les dates convenant pour les opérations agricoles, l'utilisation des sols, l'irrigation complémentaire, la protection contre le gel, la suppression de la grêle, les maladies des plantes et des animaux, la construction de bâtiments pour loger les animaux et la protection contre les incendies de forêt. Plusieurs de ces études mentionnent le coût des renseignements agrométéorologiques et des mesures de protection et indiquent les rapports coût-avantages.

Dans le chapitre 5, M. Omar donne quelques exemples des avantages et des coûts des services agrométéorologiques dans divers pays. Bien qu'il soit souvent difficile d'évaluer les coûts et les avantages en termes purement financiers, il importe de tenter de les analyser. Si l'on choisit bien les éléments de calcul et si l'on

procède à des évaluations prudentes, des erreurs relativement importantes sont acceptables. Ces études tendent à prouver que, à coût égal, les renseignements météorologiques sont plus utiles en agriculture que lorsqu'ils sont appliqués à d'autres secteurs de l'économie.

Le chapitre 6 est consacré aux études de cas faites dans des pays en développement. Comme les pays développés ont déjà défini leurs principales orientations en matière d'agriculture, le recours à la météorologie agricole y revêt souvent la forme d'une protection et d'une lutte contre les catastrophes d'origine météorologique. Dans ces pays, les pertes évitées grâce aux informations et aux avis agrométéorologiques représentent, en fait, une large part des avantages économiques de la météorologie agricole. Dans un pays en développement, au contraire, le rôle de la météorologie, du point de vue économique, consiste avant tout à contribuer au développement national en améliorant les rendements agricoles, de sorte que les activités agrométéorologiques permettent non seulement d'éviter des pertes, mais produisent aussi des avantages économiques concrets. En fait, ces avantages peuvent représenter un pourcentage important du revenu national.

Le chapitre 7 traite des gains qui pourraient résulter d'une amélioration de la qualité des renseignements agrométéorologiques. Il ressort des études de cas effectuées que, même dans l'état actuel des connaissances météorologiques, des gains importants pourraient être réalisés si les prévisions étaient plus précises. L'emploi des informations recueillies grâce aux satellites et aux nouvelles méthodes de traitement des données constitue un des moyens d'atteindre cet objectif.

Dans les conclusions de la Note technique, M. Omar souligne la complexité du processus d'évaluation des avantages que peuvent présenter pour l'agriculture les avis et les informations agrométéorologiques, sous leur forme actuelle ou améliorés. Il ne faudrait, par exemple, pas croire qu'une augmentation de la production se traduira systématiquement par un accroissement de valeur. Les facteurs économiques qui entrent en jeu en matière d'approvisionnement, de demande et de prix sont complexes. On peut toutefois raisonnablement escompter que le recours à la météorologie agricole se traduira par une utilisation plus rationnelle des sols, c'est-à-dire qu'elle contribuera à les améliorer plutôt qu'à les dégrader. En approfondissant nos connaissances des relations qui existent entre les conditions météorologiques, les sols et la vie animale et végétale, en apprenant à mieux exploiter ces connaissances, nous serons en mesure de mieux gérer nos ressources, quels que soient les caprices du temps.

РЕЗЮМЕ

Агрометеорологическая информация и консультации могут оказывать существенную помощь в увеличении количества и повышении качества продовольствия, древесины и волокон. Лучшее использование агрометеорологических ресурсов может привести не только к увеличению производства, но также может ощутимо сократить потери и ущерб, наносимые сельскохозяйственным продуктам во время транспортировки и хранения. Данный отчет рассматривает пути и средства достижения этих целей, также вводит понятие экономической ценности прикладной агрометеорологии. Знание относительной ценности агрометеорологических ресурсов поможет более реалистически подойти к предоставлению приоритета.

В главе 2 приводятся примеры метеорологической информации и способы ее применения в управлении сельским хозяйством, а также приводится ее экономическая оценка. Значительная часть материалов главы относится к процессу выработки решений с точки зрения взаимосвязи погода/сельское хозяйство.

В главе 3 приводятся детальные примеры исследований, в которых используются климатологические данные, оперативные наблюдения и прогнозы погоды. В примерах рассматривается преимущество использования паровой земли для яровых культур пшеницы по сравнению с непрерывно засеваемой, ведение сельского хозяйства на засушливых землях, ирригация полуувлажненных территорий, оборудование для сушки зерна в хранилищах и модификация условий содержания молочных коров. Другие примеры относятся к экономической оценке прогнозов погоды для посадки хлопка, сенокосов, сушки винограда, сбора урожая гороха и лесозаготовок. Эти исследования показывают, что использование метеорологической информации в сельскохозяйственном планировании и деятельности может представлять значительную ценность и что экономические выгоды часто весьма превышают затраты. Кроме того указывается, что прогнозы не обязательно должны быть идеальными, для того чтобы являться полезными.

В главе 4 рассматриваются в сжатом виде исследовательские примеры по многим вопросам, включая приемлемые данные по сельскохозяйственной деятельности, землепользованию, дополнительной ирригации, защите от заморозков, борьбе с градом, болезням растений и животных, содержанию скота и защите от лесных пожаров. Некоторые исследования показывают стоимость

агрометеорологической информации и защитных мероприятий и перечисляют примеры экономической эффективности.

В главе 5 д-р Омар приводит примеры экономической эффективности и сельского обслуживания в различных странах. Хотя часто экономическую эффективность очень трудно оценить в чисто финансовом выражении, важно делать попытки проведения такого анализа. В разумных пределах могут допускаться довольно большие погрешности в оценках экономической эффективности. Результаты исследований показывают, что использование метеорологической информации довольно высокой себестоимости в сельском хозяйстве позволяет получать более высокую экономическую эффективность, чем в случаях применения в других областях экономики.

В главе 6 приводятся примеры исследований в развивающихся странах. В развивающихся странах основными направлениями развития сельского хозяйства уже предусматривается, что агрометеорология является средством защиты и борьбы с метеорологическими бедствиями. Большая часть суммы, составляющей экономическую эффективность агрометеорологической информации и консультаций в развивающихся странах, в действительности связана с потерями, которых удалось избежать. Экономическая роль метеорологии в развивающихся странах прежде всего заключается в содействии развитию путем совершенствования отдачи сельского хозяйства; таким образом, экономические выгоды являются позитивной величиной, а не только той, которая образуется, главным образом, в результате избежания потерь. Выгоды в действительности могут являться важной частью национального дохода.

В главе 7 обсуждаются потенциальные возможности, которые могут быть реализованы в случае улучшения метеорологической информации. Исследовательские примеры указывают на то, что значительные выгоды могут быть получены даже при существующем состоянии метеорологических знаний. Применение информации, получаемой со спутников, и новые методы обработки данных представляют собой некоторые из средств достижения такого улучшения.

Завершая техническую записку, д-р Омар предупреждает об осторожности при оценке выгод для сельского хозяйства, происходящих от существующей и улучшаемой агрометеорологической информации и консультаций. Например, более высокое производство для конкретного сообщества не может быть автоматически переведено в повышенную ценность. В данном случае действуют комплексные экономические факторы, такие, как спрос, предложение и цена. Тем не менее более разумное землепользование дает определенные результаты;

следует способствовать повышению качества земель, а не их деградации. Чем лучше мы поймем взаимосвязь погоды, почв, жизни растений и животных и чем лучше мы используем наши знания об этих взаимосвязях, указывает д-р Омар, тем лучше сможем управлять нашими ресурсами даже (и тем более) при изменчивых метеорологических условиях.

RESUMEN

La información y el asesoramiento agrometeorológicos pueden contribuir de forma significativa a incrementar la cantidad y a mejorar la calidad de los productos alimenticios, los bosques y fibras. Merced a una mejor utilización de los conocimientos agrometeorológicos es posible en efecto no solamente incrementar la producción, sino también reducir de manera apreciable las pérdidas y los daños que pueden producirse durante el transporte y almacenamiento de los productos agrícolas. El presente informe trata de los métodos que deben emplearse para alcanzar estos objetivos y en el mismo se expone el concepto del mejor valor económico de las aplicaciones de la agrometeorología. El conocimiento de cada una de las aplicaciones puede permitir asignar de forma más realista prioridades a los recursos agrometeorológicos.

En el Capítulo 2 se exponen ejemplos de información meteorológica, la forma en que ésta debe ser utilizada para la gestión agrícola y se indica su valor económico. Gran parte de este capítulo versa sobre la adopción de decisiones en la esfera de la agricultura teniendo en cuenta las condiciones meteorológicas. En este capítulo se hace asimismo un estudio comparado acerca de la utilidad de las predicciones meteorológicas y la de las probabilidades climatológicas.

El Capítulo 3 contiene una descripción detallada de los estudios de casos realizados merced a datos climatológicos, observaciones en tiempo real y predicciones meteorológicas. Esos estudios se refieren al: barbecho por oposición al cultivo ininterrumpido del trigo de primavera, cultivos de secano, riegos en zonas subhúmedas, equipo de secado de los granos almacenados y modificación ambiental para la cría de vacas lecheras. Los otros casos estudiados se refieren al valor económico de las predicciones meteorológicas para las plantaciones de algodón, la henificación, el secado de la uva, la cosecha de guisantes, y la explotación de los bosques. Estos estudios demuestran que la utilización de la información meteorológica en la planificación y en las operaciones agrícolas pueden ser muy útiles y que los beneficios económicos son con frecuencia superiores a los costos, sobre todo si se tiene en cuenta que no es necesario que las predicciones sean perfectas para ser útiles.

En el Capítulo 4 se exponen sucintamente estudios de casos sobre numerosos temas, tales como las fechas más apropiadas para las operaciones agrícolas, el aprovechamiento de las tierras, los riesgos suplementarios, la protección contra las heladas, la supresión del granizo, las enfermedades de las plantas y animales, la construcción de edificios para los animales, y la protección contra los incendios forestales. En varios de esos estudios se indica el costo de la información agrometeorológica y de las medidas de protección y se mencionan las relaciones costo/beneficio.

En el Capítulo 5, el Dr. Omar cita ejemplos de los beneficios y costos de los servicios agrometeorológicos en diversos países. Aunque esos beneficios y costos son a menudo difíciles de evaluar en términos puramente financieros, es importante tratar de analizarlos. Si se seleccionan bien los elementos de cálculo y se efectúa

una evaluación prudente, pueden tolerarse errores relativamente importantes para determinar esos valores. Esos estudios tienden a demostrar que, a igual costo, la información meteorológica produce mayores beneficios económicos cuando se aplica a la agricultura que cuando se emplea en otros sectores de la economía.

El Capítulo 6 versa sobre estudios de casos llevados a cabo en países en desarrollo. Como quiera que los países desarrollados ya han definido sus principales orientaciones en materia de agricultura, la utilización de la meteorología agrícola es con frecuencia una forma de protección y de lucha contra los desastres meteorológicos. Gran parte de las ventajas considerables atribuidas al valor económico de la información y al asesoramiento agrometeorológico en los países desarrollados, representan en realidad el valor de las pérdidas que se han evitado. Por el contrario, en un país en desarrollo, la función de la meteorología, desde el punto de vista económico, es esencialmente contribuir al desarrollo mediante la obtención de mayores rendimientos agrícolas; de esta forma, no sólo se obtienen beneficios económicos positivos sino que se evitan pérdidas. De hecho, los beneficios pueden constituir un porcentaje importante de los ingresos nacionales.

El Capítulo 7 trata de las ganancias que probablemente se obtendrían con una información meteorológica mejorada. Los estudios de los casos considerados señalan que, incluso en el estado en que se hallan actualmente los conocimientos meteorológicos, se podrían lograr importantes beneficios si las predicciones fueran más exactas. La utilización de la información obtenida merced a los satélites espaciales y a las nuevas técnicas de procesamiento de datos son uno de los medios para alcanzar ese objetivo.

En las conclusiones de la presente Nota Técnica, el Dr. Omar insiste en la necesidad de mostrarse prudente en materia de evaluación de beneficios que, para la agricultura, puedan atribuirse a la información y al asesoramiento agrometeorológicos tanto en su forma actual como en forma mejorada. No debe pensarse, por ejemplo, que un aumento de la producción se transformará automáticamente en un incremento de valor. Los factores económicos que intervienen en materia de aprovisionamiento, de demanda y de precio son complejos. No obstante cabe pensar que el recurrir a la meteorología agrícola permitirá una utilización más racional de las tierras, es decir, que contribuye a mejorarlas más que a deteriorarlas. Cuanto mejor comprendamos las relaciones recíprocas que existen entre el tiempo, las tierras y la vida animal y vegetal, y mejor aprovechemos esos conocimientos, dice el Dr. Omar, tanto mejor podremos administrar nuestros recursos cualesquiera que sean los caprichos del tiempo.

CHAPTER 1

INTRODUCTION

Capricious weather coincided with surging population and increasing affluence in 1972 to create panic in food markets of the world. The usually large reserves of some basic commodities virtually vanished. Countries that routinely tap the global food chain to supplement home production found the chain weak or broken and supplies difficult to obtain. Buyers could find few sellers and prices escalated from the stress. An excess of drought, floods, freezes and other weather calamities had surprised a relatively complacent world, yet capricious weather is not an unusual thing and history recalls many crises born of weather-induced crop failures. This time, though, stress took on global significance since food reserves had dwindled to within target range of weather variability.

The shock of 1972 generated keen interest in assessing weather impact on agriculture. Governments and their populations could no longer tolerate such surprises. It was time to apply weather information to agriculture better and not just take weather and its influence for granted.

Other things remaining unchanged, weather information properly applied can help increase agricultural production, reduce product loss and damage, and improve planning and decision-making in the entire agri-business community. From producer to consumer, local governments to international organizations, we can all benefit from better application of meteorology to agriculture.

CHAPTER 2

THE ECONOMICS OF METEOROLOGICAL INFORMATION USED IN AGRICULTURAL MANAGEMENT

2.1 General

This chapter has three main parts. The first gives examples of meteorological information used in agricultural management, the second concerns the application of that information, and the third discusses the economic value of such application.

2.2 Meteorological information for agricultural management

Meteorological information may be in the form of reports of current weather conditions, forecasts of future weather events, or analyses of past weather. Alone or in combination, all can be useful in agricultural management. The information required for management decisions depends on the nature of those decisions. For example, present weather and short-period forecasts are most useful in making operating decisions, while analyses of past weather are especially useful for planning decisions. Planning decisions could be based on medium- and long-range forecasts if those forecasts were accurate enough, but often they are better based on climatological data. Predictions concerning yields, fires, diseases and pests are usually based on current and past weather and agricultural data rather than on weather forecasts.

Analysts tend to use weather data or forecasts in combination with relationships established between biological and weather parameters, that is, ecological factors. Such relationships constitute an important type of agrometeorological information.

Meteorological services issue most of the meteorological information for agricultural management. However, the farmer or other user may make his own observations. A farmer, for example, may measure soil temperature to determine when to plant his cotton, air temperature to begin frost protection, or soil moisture to determine irrigation needs.

Efficient management depends on useful, timely information presented in an easy-to-understand form.

2.3 Use of meteorological information in agricultural management

McQuigg (Figure 1) created a simple flow chart of the weather-sensitive process under management. He presents two flows: a flow of actual events, represented in the figure by solid lines, and a flow of information, represented by dashed lines. The latter flow can be neglected because decisions may be made without information or by ignoring information. Direct economic effects are determined not by mere supply of information but by actual weather and non-weather events. Information helps the manager reach the decision that will prove most profitable under actual circumstances, for example, by choosing the best time for certain operations, or selecting the best plant varieties or livestock breeds for the anticipated conditions. Meteorological information is therefore of economic value (the outcome is better than it would otherwise be) only through its effective use in the decision process. For this to occur, it is necessary that managers receive information in suitable time and form to translate it into profitable action. Effective application depends also on management knowledge of meteorological/agricultural interrelationships.

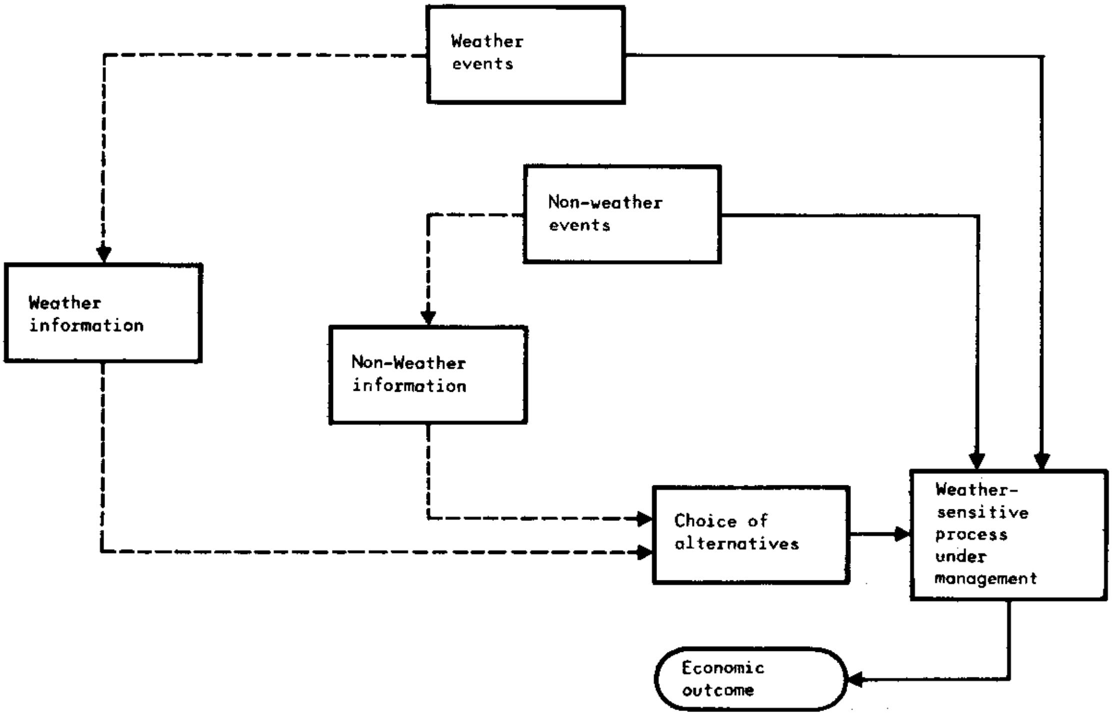

Figure 1 – Schematic outline of the role of management in agriculture (after McQuigg, 1968)

McQuigg (1965) reviewed literature concerning decision-making in weather/agriculture relations, including two pioneering studies of the 1950s. Thompson (1952) pointed out that probability forecasts are better suited to decision-making than categorical forecasts. Thompson and Brier (1955) discussed a method of analysis designed to measure the economic utility of weather forecasts. The method uses the cost/loss ratio, comparing the cost of protection from adverse weather to the loss suffered if no protective measures are taken. When the probability of adverse weather loss is greater than protective cost, obviously protective measures are in order.

Gringorten (1959) developed a model relating possible courses of action to various weather situations. Nelson and Winter (1960) studied a number of decision situations and gave some upper limits on the value of weather forecasts. Gleeson (1960) studied the multiclass prediction problem in which the upper and lower confidence limits of the relative frequencies of these classes are known. He described two decision strategies based partly on the theory of games. Miller (1962) approached the decision problem from the point of view of multiple discriminant analysis. Epstein (1962) studied the problem of decision-making in applied meteorology, considering subjective analysis with a Bayesian approach. Glahn (1964) suggested other methods using Bayes' theorem for arriving at optimum decisions.

Some workers applied decision theory to weather-sensitive agricultural problems: McQuigg and Doll (1961) on grain drying; Kolb and Rapp (1962) on raisin drying; and McQuigg, Calvert and Decker (1965) on cotton planting. These and other examples are discussed in Chapter 3 of this report.

McQuigg (1965) discussed in some detail the relation between weather and decision-making. Various workers including McQuigg (1965), Glahn (1964), and Nelson and Winter (1960) studied the decision problem in matrix form.

McQuigg (1968) gave a useful review of problems, progress and opportunities in the use of meteorological information in agricultural management. Apart from decision theory, he stressed the importance of simulation modelling as a tool applied to weather-sensitive agricultural management problems. If the simulation model is reasonably representative of the activity studied, then conditions can be varied mathematically and the results analysed. Chapter 3 includes some simulation-model case studies. McQuigg concluded that there is an urgent need for economists, statisticians and meteorologists to help managers make efficient use of meteorological information. He encouraged researchers to develop more accurate evaluations of the economic consequences of exercising options in decision matrices.

What is the decision matrix?

Consider a weather-sensitive decision process. A manager examines a relevant set of options and determines the consequences of weather events he expects to occur. Table I illustrates a decision matrix in which a_i is the i'th alternative, Ej is the j'th weather event and c_{ij} is the consequence a_i will have if E_j occurs. Generally, a weather-sensitive decision will be more successful if the available choices and relevant weather events are more clearly defined. If differences between consequences are small, it may not matter which choices are made. If differences are important, the manager's decision depends on his objectives. For example, if he wants to gain the largest possible profit, and he has enough resources to survive a temporary loss, he might accept high risks that would not be acceptable if he had few resources. Choice of action will depend on knowledge of what weather will occur at the time of the agricultural event. If this knowledge is perfect, the manager simply makes the choice that best suits his objective. If he makes the decision shortly before a weather event, with good prospects of a nearly perfect forecast, the choice is simple. If the decision must be made a long time before the weather event, a weather forecast might be less useful than climatology. Choices, then, can be judged according to expected values of the consequences determined from climatological probabilities. If probabilities of weather events are unknown, a manager can apply game theory to make a decision that minimizes loss or maximizes profit.

TABLE I

Interactions between weather events and choice of alternatives

(after McQuigg, 1968)

Act	Event		
	E_i.........	E_j.........	E_n.........
a_1	c_{1i}........	c_{1j}........	c_{1n}........
...	....	....	....
a_i	c_{ii}........	c_{ij}........	c_{in}........
...	....	....	....
a_m	c_{mi}........	c_{mj}........	c_{mn}........

The decision matrix becomes more complex when climatological probabilities are expressed in confidence levels, or if forecasts are expressed in a range of accuracies. McQuigg (1965) demonstrated that forecasts do not have to be perfect to have economic value. Gringorten (1959), Epstein (1962), and Glahn (1964) discussed other methods of decision based on matrices associated with probability forecasts.

Proving numerical values for consequences in the decision matrix is the greatest difficulty when making profitable weather-sensitive decisions. Another is ensuring that the decision matrix includes all relevant choices and weather events. Case studies in Chapter 3 present examples of numerical evaluation.

2.4 Economic value of meteorological information

Thompson and Brier (1955) defined a technique to measure economic value of weather forecasts. It is based on operational risks associated with protective measures employed against adverse weather. The authors showed that a decision to protect or not protect should be made according to this criterion:

$$P \begin{matrix} > \\ = \\ < \end{matrix} \frac{C}{L} \quad \begin{matrix} \text{Protect} \\ \text{Either course} \\ \text{Not protect} \end{matrix}$$

where P = "probability" of adverse weather = $\frac{f_w}{N}$;

f_w = frequency of adverse weather;

N = number of days of operation if protective measures are taken;

C = gain realized each day when adverse weather occurs and protective measures are taken;

L = loss suffered each day when adverse weather occurs and no protective measures are taken.

They also gave expressions for both categorical and probability forecasts. For example, the economic value for a series of categorical forecasts (N) is considered more than for climatology when:

$$\frac{a+c}{N} \left(\frac{C}{L} - \frac{c}{a+c} \right) \qquad \text{when } P_c \geqslant \frac{C}{L}$$

$$\frac{a+c}{N} \left(\frac{C}{L} - \frac{c}{a+c} \right) + \left(P_c - \frac{C}{L}\right) \qquad \text{when } P_c \leqslant \frac{C}{L}$$

where P_c is the climatological probability of observing a critical weather event = $\frac{c+d}{N}$;

a,b,c,d represent frequencies indicated in Table II, the contingency table with results of N categorical forecasts.

W and No W indicate occurrence and non-occurrence of critical weather events.

TABLE II

Generalized two-class categorical forecast contingency table

(after Thompson and Brier, 1955)

		FORECAST		
		No W	W	Total
OBSERVED	No W	a	b	a + b
	W	c	d	c + d
	Total	a + c	b + d	N = a+b+c+d

Economic value for probability forecasts is expressed in the same way as categorical forecasts. The results of probability forecasts are in Table III, where the decision to forecast W or No W is based on the value of C/L.

TABLE III

Generalized contingency table for use with probability forecasts

(after Thompson and Brier, 1955)

		FORECAST PROBABILITY		
		$P \leqslant C/L$	$P \geqslant C/L$	Total
OBSERVED	No W	a	b	a + b
	W	c	d	c + d
	Total	a + c	b + d	N = a+b+c+d

Thompson (1962, 1968) applied these concepts to express economic gain (a) if forecasts were perfect, and (b) with optimum use of current weather information.

Thompson assumed that C/L for a national economy assumes all values between zero and unity. He also assumed that all operations with different values of C/L are equally likely and important. He then assessed potential economic gain applied to actual forecasts made for locations in the U.S.A. He showed that weather losses could be cut by five to six per cent in situation (a) and by an additional two to six per cent in (b) (Table IV). These results apply to perfect forecasts made approximately 24 to 36 hours in advance. The economic gains from improvements in scientific knowledge and in operating decisions appeared to be of about the same order of magnitude regardless of the weather element or location.

TABLE IV

Mean economic gains (in units of potential loss) from scientific advances and operational improvements (after Thompson, 1968)

FORECAST	Scientific advances	Operational improvements	Total gains
Rainfall, Salt Lake City	.05	.04	.09
Rainfall, San Francisco	.06	.04	.10
Temperatures, Washington, D.C.	.05	.06	.11
General weather, North-east U.S.	.05	.02	.07

Thompson's work may be used to obtain the total potential gain for an economic unit, such as agriculture, by applying the reduced-loss percentages to losses associated with the appropriate weather element, location and forecast period. Such estimates should be useful for assessing potential economic value of improved weather forecasts. Note that results obtained apply only to avoidable loss since the techniques depend on protection against adverse weather.

Nelson and Winter (1964) established a model in the form of a game played by a firm against "Mother Nature". In all weather conditions, the firm attempts to carry out activities that lead to highest gains or lowest losses, by using climatological data and weather forecasts. The firm faces two weather states: W_1, unfavourable, and W_2, favourable. It has the option to protect against expected adverse weather or not to protect. A scheme to determine economic value of forecasts follows:

$$\pi_2 \, (C - \pi_{12} L) \quad \text{when } P_c > C/L$$

and

$$\pi_1 \, (\pi_{11} L - C) \quad \text{when } P_c < C/L$$

where P_c, C and L are as in Thompson and Brier's expressions for the economic value of forecasts; and

π_1 = the relative frequency of forecast of W_1;

π_2 = 1 - π_1 the relative frequency of forecast of W_2;

π_{11} = the conditional probability of W_1 when there is a forecast of W_1;

π_{21} = 1 - π_{11} = the conditional probability of W_2 when there is a forecast of W_1;

π_{12} = the conditional probability of W_1 when there is a W_2 forecast;

π_{22} = 1 - π_{12} = the conditional probability of W_2 when there is a W_2 forecast.

A perfect forecast system would have the following parameter values:

$$\Pi_1 = P_c,\ \Pi_2 = 1-P_c,\ \Pi_{11} = 1,\ \Pi_{21} = \Pi_{12} = 0,\ \Pi_{22} = 1$$

Maximum economic gain from improved forecasts may be calculated by subtracting the value of the existing system from the value of the perfect system.

McQuigg and Thompson (1966) modified a thesis advanced by other workers: that meteorological information has, or accrues, economic value because it makes possible better management decisions in a weather-sensitive process. They used a simulation model to manage the flow of natural gas in a city. They concluded that a manager must have a sufficient knowledge of weather and energy-use relationships if more accurate weather forecasts are to lead to better decisions and savings. A manager must be able to translate meteorological information into operational terms.

Murphy (1966) studied utility of probability forecasts when a manager's knowledge of the cost/loss ratio is incomplete and when knowledge is expressed in uniform distribution. He showed that utility is linearly related to the validity of the prediction as measured by the probability score (Brier, 1950). Murphy concluded that the probability score is a suitable measure not only for empirical but also for operational evaluation.

Murphy (1969a) studied measures of utility when knowledge of the cost/loss ratio is expressed in probability terms. He described measures in which knowledge is expressed in a beta distribution, making it often impossible for the evaluator to express his knowledge of the cost/loss ratio in a suitable form.

Further work by Murphy (1969b) indicated that a cost/loss ratio, as a random variable with a probability distribution, can be useful for scoring; Murphy therefore urged the weather forecaster to make statements according to his judgement without hedging.

Anderson (1973) studied the economic value of extended-term forecasts. He considered that a firm using these forecasts has two protection choices: A_1 can be completed in a short period of time, and A_2 requires longer time so that $C_2 < C_1 < L$. Anderson expressed the difference in value between two forecasting systems; one, short-term, giving only enough lead time to complete A_1; the other, extended-term, giving enough time to complete A_1 or A_2. Using the parameters of Nelson and Winter (1964) and priming the parameters of extended-term forecasts, Anderson defined the relative value of the extended-term forecast over the short-term as:

$$\left[\Pi_2 (C_2 - \Pi_{12} L)\right] - \left[(C_2 - C_1) + \Pi_2 (C_1 - \Pi_{12} L)\right] \quad \text{when } P_1 > C_2/L$$

and $$\Pi_1 (\Pi_{11}L - C_2) - \Pi_1 (\Pi_{11}L - C_1) \quad \text{when } P_1 < C_2/L$$

In each case, Anderson expressed differences in value between the two systems caused by accuracy alone, and caused by increased lead time of the extended-term forecast over that of the short-term forecast. The gap between accuracy and lead time suggests ways to improve forecasts.

Anderson also discussed a more complicated model that makes possible the introduction of new information during decision-making. He gave graphic analysis of weather forecasting systems showing the potential for improvements, the changes in accuracy and frequency necessary to increase the value of a new forecast, and the relation between relative sizes of forecast parameters and their economic value.

Economic value of weather information on a farm depends, after all, on the ability of a farm manager to select among decision choices. Ewalt, Wiersma and Miller (1973) undertook a pioneering study of this factor to evaluate the usefulness of precipitation and field condition forecasts to farm operators in Indiana, U.S.A. They studied relationships between farm operators' assessments of forecasts, soil characteristics and the accuracy of precipitation forecasts. They measured the value of each type of forecast on a scale of one to five.

Two-thirds of the operators interviewed used precipitation and field condition forecasts; they valued both forecasts more highly than did the remaining one-third who used only precipitation forecasts. Both forecasts improved in value with increasing soil water-holding capacity and with increasing tendency for the soil to form clods, seal, and develop tillage pans.

Farmers who used both types of forecasts valued them about equally for decisions regarding major field operations during the crop season. However, for general management decisions, precipitation forecasts were more valuable than the field-condition forecasts.

CHAPTER 3

DETAILED CASE STUDIES

3.1 General

Climatological data, real-time observations and weather forecasts can help management to estimate the economic values of different choices in making profitable agricultural decisions. Ten case studies are described: five deal with climatological data and five with weather forecasts.

The climatology cases concern: fallow-seeded and continuous spring wheat, dry-land farming, irrigation in sub-humid areas, in-storage grain-drying equipment, and environment modification of dairy-cow housing. Other cases concern the economic value of weather forecasts to cotton planting (including real-time observations), haying, raisin drying, pea harvesting and forest logging.

3.2 Case studies

3.2.1 Fallow and continuous spring wheat - Canada

Baier (1972) described an agroclimatic probability study of fallow-seeded and continuous spring wheat in southern Saskatchewan, Canada. He applied a meteorological soil water-budgeting technique (versatile budget) to estimate soil moisture. As input, he used daily estimates of potential evapotranspiration and observed precipitation (Baier and Robertson, 1966). He verified calculated estimates of spring soil moisture on fallow and on stubble lands by comparing them with 20 years of observed data. Estimates correlated significantly with corresponding observations. Baier predicted probable yields of fallow-seeded wheat (two-year rotation) and continuous wheat from estimated spring soil moisture and observed seasonal precipitation. He used a regression equation developed by Lahane and Staple (1965). Yields from continuous wheat were about 71 per cent of those from fallow wheat.

Baier evaluated average and probable net returns from fallow wheat and continuous wheat using estimated yields and data on production costs published by Mackenzie (1968). Average annual net returns per cultivated acre (0.4 ha) varied from Can $7.07 to $11.98 for fallow wheat and $9.87 to $16.59 for continuous wheat when based on farm wheat prices varying from $1.35 to $1.90 a bushel (35 l) (Table V). In three out of ten years, net returns from continuous wheat were less than those from fallow wheat, but in the remaining years net returns from continuous wheat exceeded those from fallow wheat. Table VI shows the number of years in ten when net returns exceeded selected threshold values, using an average wheat price of $1.65 a bushel. Profit occurred in eight years from continuous wheat and in nine years from fallow wheat, or a loss in two years and one year respectively. On the other hand, continuous wheat reached a threshold value of $15 in five years, fallow wheat in only three.

TABLE V

Probable annual net returns ($) from fallow-seeded wheat in two-year rotation and continuous wheat per cultivated acre for five farm wheat prices

(after Baier, 1972)

Practice	Wheat price per bushel	Probability				
		10	25	50	75	100
Fallow wheat	1.35	-1.42	2.63	7.07	11.51	15.55
	1.50	-1.13	3.36	8.30	13.23	17.73
	1.65	-0.84	4.10	9.53	14.95	19.89
	1.80	-0.56	4.83	10.76	16.68	22.07
	1.95	-0.27	5.57	11.98	18.40	24.24
Continuous wheat	1.35	-6.54	1.28	9.87	18.46	26.28
	1.50	-6.69	2.00	11.55	21.09	27.78
	1.65	-6.83	2.73	13.23	23.73	33.29
	1.80	-6.98	3.45	14.91	26.36	36.79
	1.95	-7.12	4.18	16.59	29.00	40.29

TABLE VI

Number of years in ten in which net returns exceeded the indicated threshold values

(after Baier, 1972)

Threshold values (Can $)	Two-year rotation fallow	Continuous wheat
0	9	8
5	7	7
10	5	6
15	3	5
20	1	3
25	-	2
30	-	1

Baier was able to predict in spring the likely net return from continuous or fallow wheat, for different wheat prices, by using spring soil moisture St and growing season precipitation Rn. Soil moisture could be determined by actual field measurements or by climatic water-budget techniques. Growing season precipitation could be estimated from climatological data using a selected probability level, or from a long-range weather forecast, or a combination of these. Fallow and continuous wheat apparently needed 150 mm of water before the Saskatchewan farmers realized any net return.

By studying the relationship between total available water ($St+R_n$) and net returns, we can determine the value of each additional 25 mm of water above 150 mm. Baier gave value for each additional 25 mm of water to fallow and continuous wheat, based on farm wheat prices of $1.35 to $1.95 a bushel. Values for continuous wheat are higher than for fallow wheat because continuous wheat has no idle land between crop years.

3.2.2 Wheat yield relationships - Israel

Lomas (1972) reported rainfall and wheat-yield relationships for dry-land farming in the arid northern Negev in Israel. He analysed these relationships by different methods (including Fisher's orthogonal polynomial method (Fisher, 1924)) to estimate the effect on yield of a unit change in rainfall. From the response curve Lomas obtained using Fisher's method, he calculated annual wheat yields for five stations with long-term rainfall data. Mean annual rainfall varied from 200 to 411 mm and the study assumed the agro-technology level of 1970. Lomas then determined probability of given wheat yields at each station. Figure 2 shows the probability of recovering production costs or making 20 per cent gross profit or loss for these

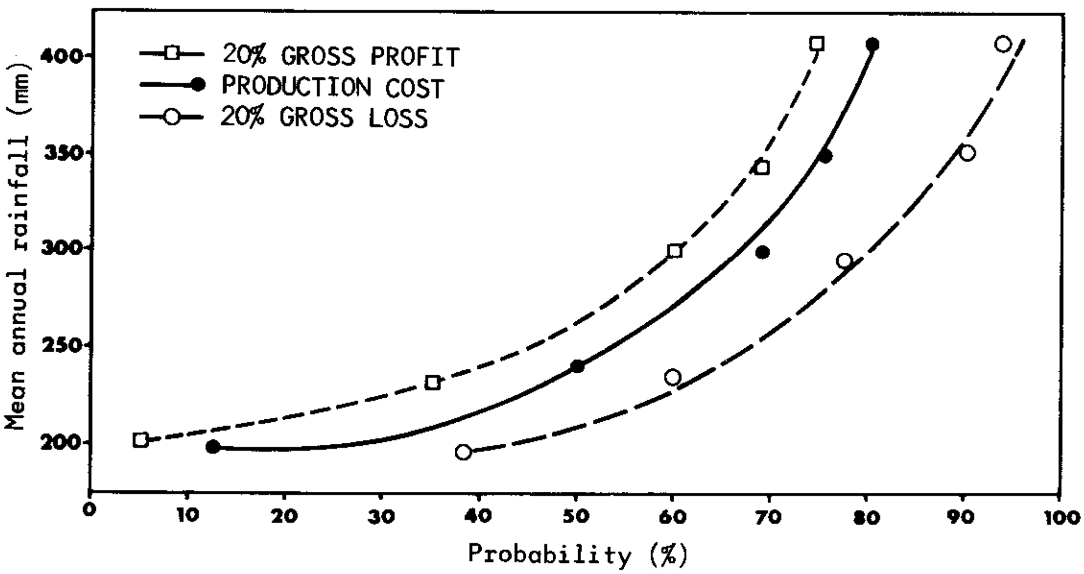

Figure 2 - The probability of recovering production costs or making a 20 per cent gross profit or loss on wheat cultivation in the northern Negev, Israel, (prices 1970/1971) (after Lomas, 1972).

stations. The report provides probability curves for changing economic circumstances to show the long-term prospects of dry-land wheat farming in the northern Negev. Twenty per cent gross profit could be obtained in seven of every ten years in areas with average annual rainfall of at least 300 mm. In areas of lower average annual rainfall, irrigation would be essential.

3.2.3 Supplemental irrigation of corn (maize) - U.S.A.

There is increasing irrigation of crops in sub-humid areas and a consequent need to justify equipment investments. In Illinois, U.S.A., Asopa, Guise, and Swanson (1973) studied the economics of supplemental irrigation of corn, its influence on income, and year-to-year income variations. They established a relationship between yields, temperature, and rainfall, based on 54 years of crop and weather data.

Specifically, they analysed the yield/moisture relationship during a 45-day period of active growth, centred about the tasseling date, and divided this period into five nine-day groups. Tasseling date was determined by a method suggested by Stauber, Zuber and Decker (1968), i.e. accumulation from planting date of 1839 degree days (base 13°C). Two approaches were used: dynamic programming and moisture deficit. The dynamic programming model applied functional equations of multi-stage decision theory to analyse the problem of operation in recursive form, subject to stochastic régimes. An optimal feedback scheme maximized expected revenue, to obtain the global optimum. Amount of water to be applied in any nine-day period depended on the crop and soil moisture at the beginning of each period. The moisture-deficit approach assumed that variations in yield between irrigated and unirrigated crops were due to variations in moisture available to the crops.

By applying the relevant meteorological variables, Asopa et al. (1973) predicted unirrigated crop yields for each year. They considered the amount of moisture in the year with the highest predicted yield as ideal. A moisture deficit for each year was obtained by subtracting actual rainfall in a given nine-day period from the rainfall of the corresponding period in the "ideal year". If the difference was negative, it was considered zero. Yields were again predicted for each year on the assumption that supplemental irrigation removes moisture deficits. Predicted yields enabled the workers to calculate incomes from unirrigated and irrigated crops, figuring US $1 per acre inch of irrigation.

In this study, Asopa et al. used four moisture-deficit models. The first, the actual moisture-deficit model, removed moisture deficits by applying irrigation. The second, the adjusted moisture-deficit model, considered that moisture deficits exceeding 50 mm equaled 50 mm and moisture deficits less than 13 mm equaled zero. The third, the rule-of-thumb model, irrigated crops with 25 mm of water each nine-day period, unless it rained that much during the period. And the fourth, the modified rule-of-thumb model, formulated levels of natural precipitation, in order to conform to discrete water applications used with the dynamic programming model.

Table VII shows mean income resulting from supplementary irrigation according to different models, at a rate of US $1.13 a bushel. To allow for irrigation equipment cost, $20 per acre has been subtracted. Except with the rule-of-thumb model, income increased with supplementary irrigation. It is noteworthy that income from the dynamic programming model was highest among the different models, although only slightly higher than the actual moisture-deficit model. The dynamic programming model had a 50 mm maximum irrigation limit in each period, while the moisture-deficit models did not. The moisture-deficit models over-estimated income. Taking into account the large approximations in the moisture-deficit models and the fact that these models require exact knowledge of rainfall occurring in each period, Asopa et al. recommended the dynamic programming model as the most profitable and realistic.

TABLE VII

Effect of irrigation on mean income from corn

(after Baier, 1972)

Model	Mean income (US $) per acre	
	Before irrigation	After irrigation
Actual moisture deficit	78.94	106.32
Adjusted moisture deficit	78.94	92.69
Dynamic programming	78.94	107.74
First rule-of-thumb	78.94	74.20
Modified rule-of-thumb	78.94	85.29

Table VIII gives the variance of expected returns as affected by supplementary irrigation. Compared with the other models, dynamic programming produced the lowest relative and absolute income variances.

The authors concluded that there was a need for more detailed formulation of the relationship between crop yield and meteorological parameters and for investment study, to reach more precise irrigation policies.

3.2.4 Grain drying - U.S.A.

If ripened corn (maize) is left in the field to become dry enough for safe storage, substantial losses of grain may occur during harvest. Losses can be decreased by harvesting earlier, when the grain has a higher moisture content, at risk of spoiling some grain during storage. Use of in-storage grain-drying equipment reduces both the loss of grain during harvest and the possibility of spoilage.

McQuigg and Doll (1961) studied the profitability of installing grain-drying equipment in Columbia, Missouri (U.S.A.). They analysed alternatives. First, they considered installing no drying equipment, harvesting grain dried to 17 per cent moisture, and selling it immediately on the open market. As an alternative, they considered installing drying bins employing either natural air or supplemental heat. Corn was assumed to be picked at 25 per cent moisture content, dried in bins to 14 per cent moisture, and stored at a guaranteed price of US $1.14 a bushel. McQuigg and Doll reckoned certain costs for drying, including supplemental heat and labour. They also calculated 10 per cent field loss using a picker sheller with corn moisture at 24 per cent and 15 per cent loss with moisture at 17 per cent.

TABLE VIII

Effect of supplemental irrigation on the variance of expected returns

(after Asopa, Guise and Swanson, 1973)

	Without irrigation	With irrigation				
		First rule of-thumb	Modified rule-of-thumb	Dynamic pro-gramming	Adjusted moisture deficit	Actual moisture deficit
Standard deviation	18.86	23.50	27.56	17.24	20.14	17.83
Variance	355.78	522.31	759.56	297.21	405.80	317.99
Coefficient of variation	0.24	0.25	0.26	0.14	0.18	0.14

Table IX lists open market corn prices at harvest necessary if returns from in-storage natural air drying are to equal those from direct sale from the field. If open market prices are lower than the values listed, grain-drying equipment is profitable. Prices are based on the number of bins used, number of bins installed, and number of days required to dry grain from 25 per cent to 14 per cent moisture. Drying time was related to dry- and wet-bulb air temperatures, using a mathematical model developed by Brooker and McQuigg (1960). Based on physical and engineering concepts, the model considers moisture content of the grain and temperature and moisture content of the air forced through the grain bin. From 25 years of weather records, they calculated the frequency distribution of the number of days needed to dry a bin of grain from 25 per cent to 14 per cent moisture.

TABLE IX

Open market corn prices (in US $) that must prevail at harvest time if returns from in-storage drying are to equal returns from direct sale from the field at harvest time.

(after McQuigg and Doll, 1961)

Number of bins installed	Number of days required to dry bin load of grain			
	6	10	14	18
	One bin used. Total yield 2222 bu.			
1	1.10	1.10	1.09	1.08
2	1.03	1.02	1.01	1.00
3	0.95	0.94	0.93	0.92
4	0.88	0.87	0.86	0.85
5	0.80	0.79	0.78	0.77
	Two bins used. Total yield 4444 bu.			
2	1.10	1.09	1.08	1.07
3	1.06	1.05	1.04	1.03
4	1.02	1.02	1.00	1.00
5	0.99	0.98	0.97	0.96
	Three bins used. Total yield 6666 bu.			
3	1.10	1.09	1.08	1.07
4	1.07	1.06	1.06	1.05
5	1.05	1.04	1.03	1.02
	Four bins used. Total yield 8888 bu.			
4	1.10	1.09	1.08	1.07
5	1.08	1.06	1.06	1.05
	Five bins used. Total yield 11110 bu.			
5	1.10	1.09	1.09	1.07

Table X indicates expected profits from drying one to five bins of corn, using natural air grain-drying equipment, at market prices of $0.98 and $0.94 a bushel. For supplemental heat drying with a 10° C increase in air temperature, though, expected profit, for example, would be only $22 with a $0.98 market price and one of two bins filled, while the profit for corresponding natural air drying would be $50.

TABLE X

Profit expected (in US $) from drying one to five bin loads of corn, using natural air grain-drying equipment, based on a support price of $1.14/bu. of corn, (P is the price/bu. on the open market at harvest time)

(after McQuigg and Doll, 1961)

Number of bins installed	Number of bins used				
	1	2	3	4	5
		P = $ 0.98			
1	180				
2	50	359			
3	- 70	234	539		
4	-195	109	414	719	
5	-320	- 16	389	594	899
		P = $ 0.94			
1	247				
2	122	493			
3	- 3	368	740		
4	-128	243	615	987	
5	-253	118	490	862	1234

Brooker and McQuigg (1963) applied the same model to obtain expected drying times and variations in expected values for natural air drying and heated air drying with temperature increases of 10°C and 16°C.

3.2.5 Weather and milk production - U.S.A.

Hahn and McQuigg (1967) combined weather events and livestock responses with climatological data to estimate milk production of dairy cows. Productivity of cows decreases due to summer heat. Knowledge of weather impact on milk production provides the manager with information for selecting the most profitable environment for his herd.

Waggoner (1965) combined probability of a weather event with the biological response to that event to give the probability of the response. Probabilities of many weather events can be estimated from climatological data, and so a quantitative relationship between livestock production and weather events enables a manager to estimate production losses. Berry, Shanklin and Johnson (1964) described a functional relationship for milk production of dairy cows:

$$M\ Dec = 1.075 - 1.736\ NL + 0.02474\ (NL)\ (THI)$$

where M Dec = absolute decline in milk production in kg per day-cow;

NL = normal level of production in kg per day;

THI = daily mean Temperature-Humidity Index value

$= t_{db} + 0.36\ t_{dp} + 41.2;$

where t_{db} = dry-bulb temperature in ^{o}C;

t_{dp} = dew-point temperature in ^{o}C.

Hahn and McQuigg (1967) combined the relationship in nomogram form with the empirical probability curve for THI during 1 June - 30 September, the period of greatest production decline for most of the U.S.A. Figure 3 is an example of this exercise, using climatological records for Columbia, Missouri. By integrating the losses over the summer period, Hahn and Osburn (1969) estimated production decline for cows at various locations.

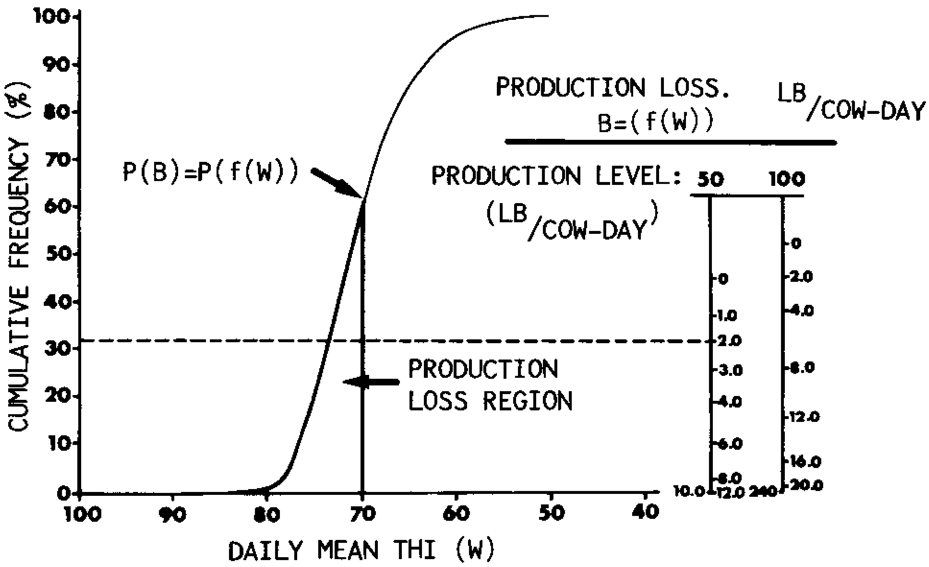

Figure 3 - Empirical probability curve for production decline of Holstein cows at Columbia, Missouri based on a 20-year distribution function of daily mean THI values (1 June to 30 September). Direct evaluation can be made for the chances of production losses for cows of two levels of production. For example, the probability of a 23 kg (50 lb) per producer declining in production by 1 kg (2 lb) per day is 0.32; i.e., on about one day in three during the summer months the cow would experience this summer production loss (after Hahn, Osburn and McQuigg, 1971)

Hahn, Osburn and McQuigg (1971) used the traditional capital budgeting technique of discounting future returns to a present value to compare two methods of environmental modification: complete environmental control and evaporative cooling. For rapid calculation of benefit/cost ratios for the two methods, they developed equations to relate variables affecting fixed and variable costs. For example, they developed benefit/cost ratios for a 100-cow herd at Memphis, Tennessee. Average ratios were about 1 : 10 for complete control and about 2 : 30 for evaporative cooling. Figure 4 shows isopleths of profitability, or break-even points for a manager, obtained by equating net returns to initial costs of air-conditioning and evaporative cooling. For areas north of the air-conditioning isopleth, costs of environmental control exceeded benefits. This demonstrates that the optimum environment for production and feed efficiency is not necessarily the economic optimum.

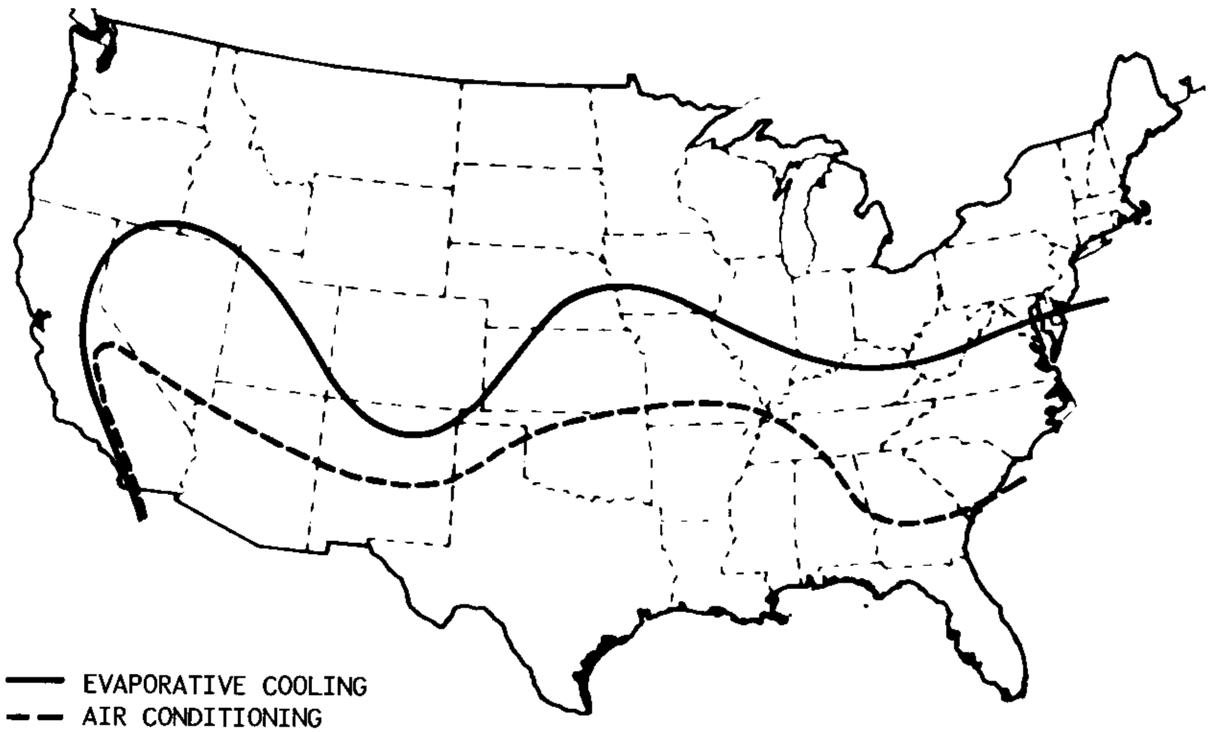

Figure 4 - Isopleths of profitability for two environmental modification methods in the United States - cows with 32 kg/day normal production level; reasonable values for input variables (after Hahn, Osburn and McQuigg, 1971)

Hahn, McQuigg and Osburn (1972) investigated the summer environmental modification for dairy-cow housing in Missouri, comparing complete air-conditioning, partial air-conditioning, and evaporative cooling. Complete control and partial air-conditioning by mechanical refrigeration were not economically feasible. Evaporative cooling appeared to have considerable potential for profitable application, although the relatively humid climate of south-east Missouri is not very favourable to this practice. As an example, the authors gave benefit/cost ratios for a 100-cow dairy herd producing 32 kg per day at Springfield, Missouri. Average ratios were 0 : 47 for air conditioning, 0 : 62 for partial air-conditioning, and 1 : 50 for evaporative cooling. To illustrate the potential of evaporative cooling in Missouri, the study presented isopleths of yero profitability for cows of 23 and 32 kg per day normal production level. North of the isopleth evaporative cooling should not be attempted. South of the isopleth it should be considered.

3.2.6 Selection of cotton planting dates - U.S.A.

Cotton seeds often will not germinate when planted early and therefore must be replanted at additional time and expense. There are several advantages to early planting, so a farmer should plant on the earliest dates that offer low risk of re-planting. McQuigg, Calvert and Decker (1965) studied choice of planting dates for cotton in south-east Missouri. They studied growth chamber experiments and concluded that germination would be poor if soil temperature at planting depth remained below 20°C (68°F) for more than six days in a ten-day period that started at planting. Similar conditions in the field would require replanting.

The researchers used 11 years of daily precipitation and soil temperature observations to select planting dates. Figure 5 illustrates their decision model. Step I concerned dryness of the soil, determined by precipitation for two days preceding the date of decision. The answer was "yes" if both days received less than 1.3 mm (0.2 inches) of rain. In actual practice, the farmer would decide soil moisture after inspection of his field. The model took 15 April to be the earliest reasonable planting date. If the answer to Step I was "yes", then Step II was applied, involving soil temperature of the previous afternoon. The farmer might read his own soil thermometer or listen to radio reports. If Step II is "yes", then Step III follows, involving the five-day temperature forecast. The computer checks anticipated air temperatures for the five-day period, and then "forecasts" the probability of acceptable or unacceptable soil temperatures.

The model simulated several possibilities. A first run simulated Step I only: a farmer ignored both observed and forecast data and planted the first day the soil was dry enough after 15 April. Run two simulated Steps I and II; a farmer ignored weather forecasts but used observed soil temperatures. The model assumed that replanting was necessary if in the ten-day period there were more than six days with soil temperature below 20°C (68°F) at planting depth. The cost of replanting was reckoned at $5 an acre.

The following runs used Steps I, II and III. The model tested perfect temperature "forecasts" and also "forecasts" of 90, 80, 70, 60 and 50 per cent

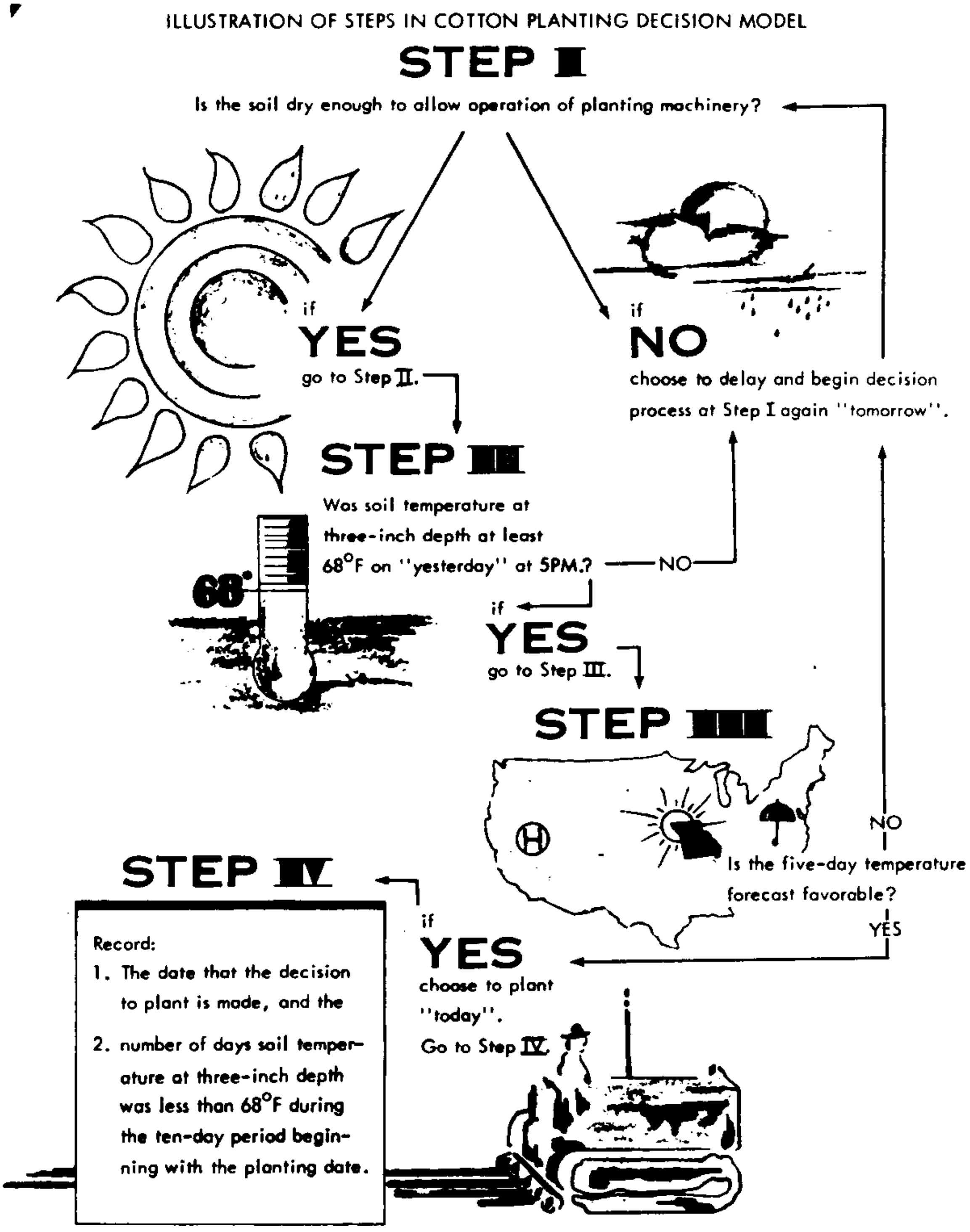

Figure 5 - Illustration of steps in cotton planting decision model (McQuigg, Calvert and Decker, 1965) (after McQuigg, 1968)

accuracy. Figure 6 displays the results and Table XI summarizes three methods of decision-making. Results indicate that, in south-east Missouri, planting cotton without observed or forecast data would lead to a replanting cost of about $3.60 per acre annually. Cost would decrease to about $1.35 an acre if daily soil temperatures were observed. When both observations and forecasts (75 per cent accurate) are used, annual costs decrease to about $0.40 an acre - an annual savings of about $3 an acre.

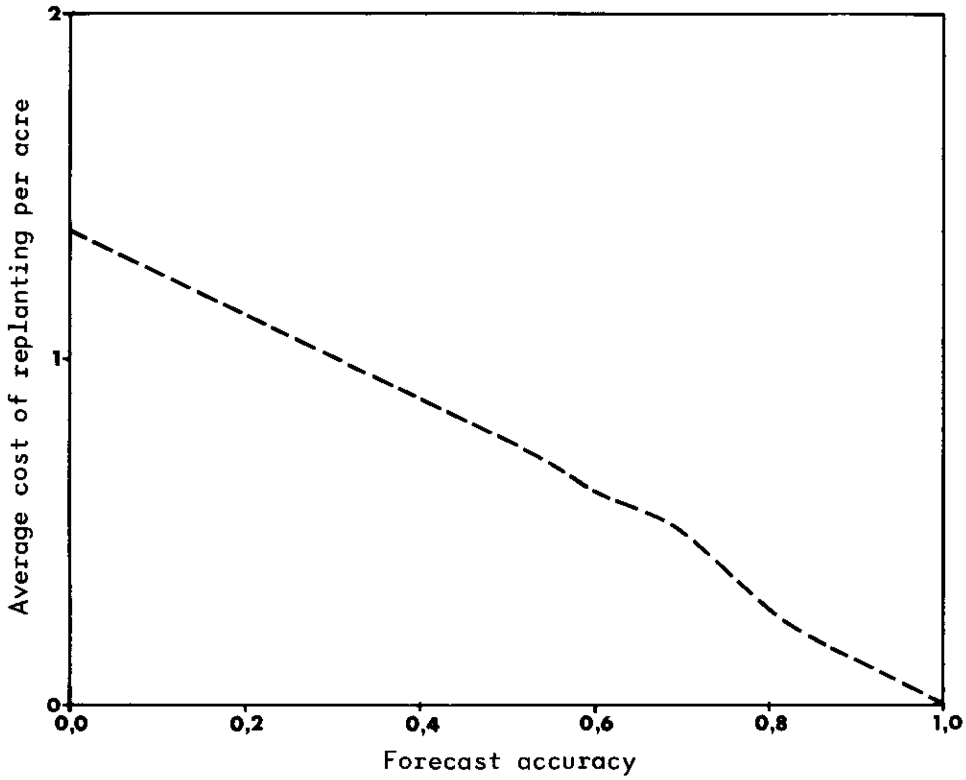

Figure 6 - Relationship between forecast accuracy and average cost of replanting cotton in the Missouri Bootheel (decision process beginning 15 April) (McQuigg, Calvert and Decker, 1965) (after McQuigg, 1968)

TABLE XI

Summary of results of different methods of decision-making on cotton planting

(after McQuigg, Calvert and Decker, 1965)

	Using no weather information	Using only observed data	Using observed and forecast data			
			Forecasts 70% right	Forecasts 80% right	Forecasts 90% right	Forecasts 100% right
Average planting date	April 17	May 2	May 6	May 9	May 10	May 18
Average annual cost of replanting per acre ($)	3.63	1.36	0.60	0.28	0.15	0.00

3.2.7 Decisions on mowing hay - U.S.A.

McQuigg (1965) studied the utility of weather forecasts for haying performed during the first ten days of June in central Missouri. Farmers need three consecutive favourable days for mowing, field curing, baling and storing. Borgman and Brooker (1961) defined a favourable day as having less than 2.5 mm of rain, at least 70 per cent possible sunshine, and less than 25 mm of rain on the previous day. Value of hay often peaks in early June and weather enhances quality and value. Borgman and Brooker's example valued high quality hay at $26 per acre. If hay is cut and more than 2.5 mm of rain occurs during the curing, value of the hay deteriorates and there are additional raking costs. They valued such hay at $19.50 per acre. Hay deteriorates if mowing is delayed during favourable weather. They valued such hay at ⩽ $24 per acre. If mowing is delayed and the weather is not favourable, the value of the crop will be determined by the amount of delay and actual weather at harvest. Net value would be ⩽ $24 per acre. Table XII shows net values in a decision matrix.

McQuigg (1965) studied three kinds of decisions to mow or not to mow:

- Decisions based on climatology alone, depending on conclusions of Borgman and Brooker (1961), had a probability of occurrence of 0.2 for three consecutive favourable days in June in central Missouri. Expected returns from the decision to mow would be ⩽ $20.80 per acre, while from the decision not to mow returns would be ⩽ $24 per acre, according to Table XIII.

TABLE XII

Hay harvest decision matrix

(after McQuigg 1965)

Alternatives	Actual weather	
	Favourable	Not favourable
Mow	\$26.00	\$19.50
Not Mow	⩽ 24.00	⩽ 24.00

TABLE XIII

Expected returns from hay harvest based on climatology

(after McQuigg 1965)

Alternative	Actual weather		
	Favourable	Not favourable	Total expected returns
Mow	\$5.20	\$15.60	⩽ \$20.80
Not mow	4.80	19.20	⩽ 24.00

- Decisions based on three-day weather forecasts and with a favourable weather forecast of 0.60 accuracy returned ⩽ \$23.40 per acre from the decision to mow, ⩽ \$24 per acre from the decision not to mow.

- Decisions based on three-day weather forecasts, but with 0.70 probability of an accurate favourable weather forecast, returned ⩽ \$24 per acre for either decision.

McQuigg concluded the ideal forecasting system would be to issue favourable forecasts only when the probability of favourable weather is ⩾ 0.70. Total expected returns from a decision to mow would thus be no lower than for a decision not to mow. And a farm manager would not be inclined to delay harvest due to a forecast for favourable weather.

3.2.8 Tailoring weather forecasts to raisin drying - U.S.A.

Kolb and Rapp (1962) showed that weather forecasts can be useful to reduce the cost of protecting drying raisins from rain in the San Joaquin Valley of central California. They also illustrated forecasts tailored to the needs of the raisin industry for increased usefulness.

Producers dry grapes on paper trays in the vineyards during three to four weeks in late summer and early autumn. Too-early harvesting leads to inferior raisins of low sugar content; if producers delay harvest, threat of rain damage increases. Damage occurs with 2.5 mm or more of rain. When rain threatens, the paper trays are rolled and stacked in vineyard rows. Protective measures cost about $6 a ton (907 kg) of raisins; the raisins were at that time valued at about $200 a ton. Based on perfect forecasts, the average protection cost would have been about $3.70 a ton per season. Assuming the producer protects each time rain is predicted, the cost in dollars per ton would be equal to 6Nr + 200 Nnr:r, where Nr is the number of rain forecasts made during the drying period and Nnr:r is the number of times during this period when rainfall was not predicted but it rained.

TABLE XIV

Forecasts and expected costs for a 28-day period as a function of the W-value selected as a cut-off point

(after Kolb and Rapp, 1962)

W-value chosen as cut-off point	Nr; rain forecasts	Nnr:r, rains occurring when no rain is forecast	$\hat{C}$, expected cost if producer protects when rain is forecast (US $)
10	6.65	0	39.90
20	4.69	0	28.14
30	3.59	0	21.54
40	2.73	0.05	26.38
50	2.44	0.07	28.64
60	1.92	0.10	31.52
70	1.39	0.17	42.34
80	0.86	0.25	55.16
90	0.48	0.33	68.88
100	0.00	0.62	124.00

Kolb and Rapp considered that forecasts can be arranged according to scale with a majority of correct no-rain forecasts at one end. This scale would give a parameter useful for relating the number of rain forecasts to the number of incorrect no-rain forecasts. The forecaster would have freedom to make more rain forecasts and less incorrect no-rain forecasts as well as the possibility of selecting the combination of forecasts that would minimize the expected cost of protection. Kolb and Rapp indicated that Jorgensen's parameter W (Jorgensen, 1949), which is the outcome of a rather complex objective forecast technique, can be useful for the selection. They applied data accumulated by Jorgensen to determine the optimum combination of forecasts. Table XIV lists results. Column 4 shows the expected cost if the producer protects whenever rain is forecast. It is clear from column 3 that, to minimize cost of protection, rainfall should be predicted whenever W is larger than 30. The expected annual cost of protection based on these forecasts would be about $22 per ton of raisins.

3.2.9 Weather forecasts and pea harvest - U.S.A.

Extended-term weather forecasts benefit pea processors. Fresh peas become worthless when they pass the number of degree-days necessary for maturity. They must be harvested as they ripen and planting is therefore staggered so that orderly harvesting is possible. More than a critical number of degree-days, due to above-normal temperatures during harvest, can cause loss of some of the pea crop. Anderson (1973) showed that extended-term forecasts of about one week can be useful to pea processors in the state of Washington (U.S.A.) by giving them enough warning to let them harvest extra acres.

Anderson determined the relationship between extra degree-days and the extra acres to be harvested, and defined an optimum planting schedule. He studied the effect on maturation rate of five extra degree-days per day over eight-day periods. This information enabled him to determine the number of acres that would ripen early during each period.

Anderson discussed three choices for a processing firm confronted with a hot spell that would ripen 100 extra acres prematurely. With the first, A_1, by applying all of its resources the firm can harvest 120 acres a day when normally they do only 100. It is possible, then, to harvest 20 of the extra acres on the day hot weather occurs and another 20 acres the following day. The remaining 60 acres are abandoned. The second choice, A_2, is to harvest 20 of the extra acres on each of the two days preceding anticipated hot weather. If hot weather actually comes, 40 of the remaining 60 extra acres can be harvested as in choice A_1, leaving only 20 acres abandoned. Choice A_3 is to harvest early as in A_2 and to contract for other firms to harvest and process the extra acres. Sometimes this is not possible as it depends on the capacity of other firms for harvesting and processing, and on the weather in their areas. Anderson constructed a game box (Figure 7) that considered these choices and used cost data determined by the firm for different possibilities.

In his study of the value of weather forecasts, Anderson assumed 0.8 accuracy of predicting hot spells, i.e. $\Pi_{22} = 0.8$. W_1 and associated parameters Π_1, Π_{11} and P_1 represent normal (or favourable) weather. It is clear that A_3 should be chosen when hot weather is forecast. When normal weather is forecast, A_1 or A_2 should be used depending on whether Π_{11} is larger or smaller than 0.9498, the point at which expected costs of A_1 and A_2 are equal. For different values of Π_{11} Anderson considered 1 as the probability of having another firm handle the extra acres.

Weather:

Choice:	W_1 (\$)	W_2 (\$)
A_1	0	13 740
A_2	400	6 180
A_3	4 000	4 000

Figure 7 - Simplified game box for pea-harvesting study

Probability of occurrence of normal weather P_1 is 0.83. Expected costs using climatology for A_2 and A_1 are:

A_2 0.83 (400) + 0.17 (6 180) = \$1 382.60

A_1 0.83 (0) + 0.17 (13 740) = \$2 235.80

A_2 is more profitable based on climatology. The value of the system is the expected cost of using climatology minus the expected cost of using the forecast, so that when Π_{11} is less than 0.9498, the value of the system is:

$$V = 1\ 382.60 - \Pi_1 (\Pi_{11} \times 400 + \Pi_{21} \times 6\ 180) - \Pi_2 (4\ 000)$$

when Π_{11} is larger than 0.9498, the value of a system is:

$$V - 1\ 382.60 - \Pi_1 (\Pi_{21} \times 13\ 740) - \Pi_2 (4\ 000)$$

Table XV summarizes maximum gains for the whole season for different Π_{11} values. These figures may be used to estimate gains in a region with weather conditions similar to those of the area studied (Skagit County, Washington). Table XVI gives the same information as Table XV except that Π_{22} is 0.9. An interesting point may be inferred from the tables: the gain from increasing Π_{22} by 0.1 is less than the gain from increasing Π_{11} by 0.2.

Anderson noted that the values in the tables were underestimates of gain because he assumed some acres would be harvested early or late; if there were extra equipment available, those acres could be harvested on time with more gain.

TABLE XV

Economic benefits for a pea-harvest season of different accuracies if $\Pi_{22} = 0.8$

(after Anderson, 1973)

Π_{11}	Total value $	Savings as a percentage of profit $	Savings to Skagit County $
0.80	126.65	0.029	493.29
0.82	244.96	0.056	952.56
0.84	490.37	0.111	1,888.11
0.86	736.48	0.167	2,840.67
0.88	1,160.17	0.263	4,473.63
0.90	1,800.76	0.408	6,940.08
0.92	2,471.39	0.560	9,525.60
0.94	3,121.58	0.708	12,043.08
0.96	4,946.44	1.122	19,085.22
0.98	6,913.95	1.568	26,671.68

Table XVI

Economic benefits for a pea-harvest season of different accuracies if $\Pi_{22} = 0.9$

(after Anderson, 1973)

Π_{11}	Total value $	Savings as a percentage of profit (%)	Savings to Skagit County $
0.80	147.74	0.034	578.34
0.82	287.26	0.065	1,105.65
0.84	580.06	0.132	2,245.32
0.86	878.97	0.199	3,384.99
0.88	1,386.75	0.314	5,341.40
0.90	2,128.96	0.483	8,215.83
0.92	2,961.22	0.671	11,413.71
0.94	3,755.16	0.852	14,492.52
0.96	5,801.60	1.316	22,385.16
0.98	7,956.67	1.804	30,686.04

3.2.10 Weather and choice of logging roads - U.S.A.

In forestry, logging is sensitive to rain. Unless gravel is applied to logging roads, they become impassably muddy with too much rain. When an area is to be logged, primary roads are customarily gravelled. Spur roads are not gravelled when loggers expect dry weather, i.e. less than 1.5 mm of rain over seven days. A spur area is usually logged in such a period. Reasonably accurate seven- to ten-day extended-term rainfall forecasts would give loggers useful information on treatment of spurs. Anderson (1973) studied information from two branches of a U.S. company to assess the usefulness of extended-term forecasts.

His first study concerned a lumber company in Springfield, Oregon. Data supplied by the company indicated that when dirt roads are used, costs are 40 per cent of those when gravelled roads are used. On the average, five per cent of their logging occurred over dirt roads. Percentages indicate that the average cost of using gravelled <u>and</u> dirt roads is 0.4 (0.05) + 1.0 (0.95) or 97 per cent of the cost when gravelled roads only are used. The current forecasting system implies a cost reduction of three per cent over climatology. Anderson constructed a game box (Figure 8) using these data and the condition that dirt spurs would not be used unless P_1 were at least 0.4 (P_1 = probability of <1.5 mm of rainfall during a seven-day period). Anderson estimated the value 1.4 in Figure 8 by solving the following equation for X:

$$P_1\,(0.4) + P_2\,X = 1.0$$

where $P_1 = 0.40$,

$P_2 = 1 - P_1 = 0.60$

	W_1 less than 1.5 mm/week	W_2 more than 1.5 mm/week
Dirt	0.4	1.4
Gravel	1.0	1.0

Figure 8 - Game box for logging study

Using climatological probabilities of dry weather by weeks and the equations from the game box, Anderson was able to obtain percentile savings in yearly costs over the current forecasting system (Table XVII) with the equation:

$$\text{per cent} = 1 - \left(\frac{52 - EV}{52} \cdot \frac{1}{0.97}\right)$$

where EV = the sum of weekly cost reductions. W_1 and associated parameter Π_{11} represent favourable weather conditions.

When $\Pi_{22} = 0.7$ then Π_{11} must be at least 0.75 for the forecasting system to be an economic improvement over the current system. Savings can be as high as 5.3 per cent of the road costs when $\Pi_{11} = 0.95$. When $\Pi_{22} = 0.8$ the corresponding values are 0.60 and 7.6 per cent.

Anderson applied the same methods to the Chehalis area of Washington State, where only four per cent of the total harvest is hauled over dirt roads, and obtained similar results. With $\Pi_{22} = 0.7$ and 0.8 the forecast system would be an economic improvement over the current system if Π_{11} is at least 0.65, and the savings can reach 2.1 per cent and 4.1 per cent respectively when $\Pi_{11} = 0.95$.

3.3 Conclusions

Use of meteorological information in agricultural planning and operations can be of considerable value, as demonstrated by the cotton planting case. The cost of this information is often appreciably lower than the economic gain.

The value of seven-to ten-day forecasts to pea processors does not seem very high, but the value given is conservative.

In those cases associated with climatological information, gains obtained should encourage exploitation of the large amount of climatological data available. Since accurate long-range weather forecasts for farmers are not yet possible, the soundest basis for long-term planning will continue to be statistical analysis of long-term climate data.

As for cases associated with weather forecasts, cotton planting and haying studies demonstrate that weather forecasts do not have to be perfect to be economically valuable. These two cases, as well as those using seven-to ten-day extended-term forecasts, indicate that increasing accuracy of forecasts leads to increasing economic value. In some cases, haying and raisin drying for example, it is possible to tailor forecasts to specific needs in order to maximize gains or minimize losses.

The utility of these case studies should encourage study in other fields.

Case studies illustrate the importance of relations between meteorological and biological factors and simulation models based on them. Sometimes information is not as complete as we might need, as in the corn irrigation case. Also, models used should not be unrealistic or vague.

To obtain economic benefits such as those illustrated by these case studies, meteorologists and farm and agri-business managers must understand the relationships between biological and meteorological factors, the meaning of the terms used and the concept of decision processes.

CHAPTER 4

BRIEF CASE STUDIES ON ECONOMIC VALUE OF AGROMETEOROLOGICAL INFORMATION AND ADVICE IN DEVELOPED COUNTRIES

4.1 General

An examination of the literature indicated that the majority of studies on economic value of agrometeorological information and advice were for developed countries. This chapter briefly describes 23 such studies. Chapter 6 presents case studies for developing countries.

The case studies in this chapter are representative of most described in the literature. Topics include: selecting dates suitable for agricultural operations, stopping cultivation of crops in unsuitable areas, irrigation, frost, plant diseases, animal diseases, animal housing, and forest fires. Several studies provide costs of agrometeorological information and benefit/cost ratios.

4.2 Selecting suitable times for agricultural operations

Mason (1968) showed in a U.K. study that judicious use of weather forecasts to choose the best times for cutting and drying hay may increase yield and quality by ten per cent and thereby increase winter milk production by two per cent. He estimated the annual value of the present imperfect service to be at least £2 million.

Mason (1966) found that use of weather forecasts to choose sowing and harvesting times for wheat and barley may increase yields by several per cent. He also estimated the annual value of the present service at about £2 million.

According to Giovanelli (1968), the losses avoided by using weather forecasts to select wine-grape harvest dates in the Bordeaux area of France are ten to fifteen per cent. Allowing for an average return of FF 5 000 per acre and for avoidable loss of ten per cent for vineyards as a whole once every five years, the annual saving would be about FF 30 million.

Thompson (1966) evaluated a pilot crop-weather project in the Mississippi Delta and found that savings for agriculture in the initial year were about US $2 million. Weather forecasts enabled farmers to avoid premature planting, permitted efficient pest control and enhanced other farm operations. Cost of the one-year project was less than US $50 000 and the benefit/cost ratio therefore about 40 : 1.

4.3 Unsuitable areas for corn (maize) in Switzerland

The Swiss Meteorological Institute prepared a climate map for corn cultivation and illustrated areas where maize was not profitable. Estimated yearly financial savings through eliminating corn in such areas amounted to Sw.fr. 5 to 6 million for seed labour machines and fertilizer. The federal research institutes and the Swiss Meteorological Institute contributed about Sw.fr. 100 000 for compilation of the map.

4.4 Irrigation

Nix and Prickett (1961) found that the values of increased yield per acre by irrigation at a likely range of costs were: for early potatoes, £50 versus £3.5 to £10; for main potato crops, £40 versus £5 to £15; for peas, £15 versus £2 to £5 Gains are obviously substantial.

Winter and Blackwall (1963) increased profit of early potatoes by £60 to £62 per acre through various rates of irrigation.

The U.S. Bureau of Reclamation and the Agricultural Research Service (USDA) developed a system for scheduling irrigation using climate, crop and soil data that provides farmers with weekly information on when to irrigate and the amount of water to apply (Jensen, Robb and Franzoy, 1969). They valued average yield increase and savings from avoiding one or two irrigations at about US $120 per hectare annually at a cost of about US $3 per hectare. The benefit/cost ratio is thus about 40 : 1.

4.5 Frost

In the U.K., Hogg (1966) described saving a potato crop valued at £3 000 by irrigating the day before a severe spring frost. Similar savings were made in Switzerland (Roten and Primault, 1964) and in France (Dessens, 1968).

Hogg (1970) also studied frost prevention through irrigation of blackcurrents at Somerset (U.K.), and estimated that £1 000 per acre would be a justified capital expenditure for frost prevention equipment and application.

Giovanelli (1968) indicated that the annual economic gain resulting from use of meteorological information to combat spring frosts in French orchards is about FF 400 per acre. In south-western France, the gain amounts to FF 4 million annually.

Primault (personal communication, 1972) described a frost-warning system developed by Perraudin in the Valais canton, Switzerland. A good warning before a frosty night in spring, with adequate frost protection, can save about Sw.fr. 5 million. When a frost warning is made and farmers start protection measures but temperatures do not drop below $0^{\circ}C$, costs can be about Sw.fr. 300 000 for machines, wages and energy. The ratio of the cost of a useless warning to the value of a good warning is about 1 : 15.

The publication "WMO helps the developing countries" (WMO-No. 307, 1971) describes a 1968 forecast of spring frost responsible for saving US $1.5 million in Hungary.

Berggren (1972) discussed an agro-topo-climatological survey of 100 square kilometers in Israel costing US $1.50 per hectare per year and applied to avocados. Avocados require an investment of US $20 000 per hectare. Frosts, expected once every four to five years, can cause production losses of 40 to 60 per cent in badly situated plantations. If the survey can help to avoid frost damage completely, the benefit/cost ratio would be about 200 : 1.

4.6 Hail suppression in the U.S.S.R.

Hobbs (1968) reported hail suppression activities in the Caucasus and Transcaucasus. Since activities began in 1964, hail damage to crops in seeded areas decreased to 20 to 33 per cent of damage in unseeded areas. The gain in seeded areas was about 30 million roubles, while the cost of the programme was 1.5 million roubles, a benefit/cost ratio of about 20 : 1.

4.7 Plant diseases

Mason (1968) credited forecasts in the U.K. on incidence of potato blight, based on meteorological information with saving at least one per cent of a crop worth £100 million a year, i.e. about £1 million.

Sussenberger (1968) described a service of the Federal Republic of Germany established in 1967 to combat potato blight. The crop was formerly sprayed on a regular schedule, but since 1967 producers have applied sprays according to meteorological conditions. If producers eliminate just one spray application they save about US $5 per hectare or about US $3.5 million throughout the country.

Giovanelli (1968) estimated that with meteorological information, Bordeaux area producers eliminated two to three pest control treatments each year in orchards and vineyards, saving FF 26 million annually. He also estimated that meteorological information in south-eastern France eliminated one treatment a year in vineyards, saving FF 21 million.

Virus of yellow disease spread by aphids can severely reduce sugar beet yields in the U.K. Mason (1968) estimated that forecasts of aphid infestation, based on past weather, can lead to annual savings of about £1 million.

4.8 Forecasting animal diseases in the United Kingdom

Mason (1968) also determined that effective veterinary action based on weather-oriented forecasts of incidence of four major animal diseases saved producers about £4 million a year.

4.9 Animal housing in the Federal Republic of Germany and Switzerland

According to Primault (personal communications, 1972), experts are working to standardize animal housing in the Federal Republic of Germany and Switzerland. Thanks to new weather maps displaying heat and cold indices, builders can save about Sw.fr. 20 per cubic metre while constructing new buildings or making alterations. The Swiss Meteorological Institute thus contributes about Sw.fr. 80 000 to the project which covers 4 000 cubic metres.

4.10 Protection against forest fires

Giovanelli (1968) estimated that net savings due to using weather reports for combatting forest fires in Mediterranean France amounted to at least FF 2 million per year. And Gibbs (1968) estimated that meteorological forecasts for prevention and control of Australian bush and timber fires save about A $34 million annually.

4.11 Conclusions

These applications of meteorology to agriculture demonstrate considerable economic value; benefit/cost ratios are usually large. Furthermore, they illustrate and suggest the diverse ways that meteorology can be applied to agriculture: for scheduling farm and processing operations, planning animal housing and land use, pest prediction and control, marketing and buying strategies and tactics, optimizing seed and fertilizer use, predicting yields and product quality, storage methods and facilities, irrigation methods and needs, frost and other hazardous weather protection, selecting transport equipment and routine, suppresion of hail and other harmful events, precipitation enhancement, forest operations and fire control, grassland management, water conservation and storage, soil conservation, and many others. The possibilities seem almost unlimited.

CHAPTER 5

BENEFITS AND COSTS OF AGROMETEOROLOGICAL SERVICES

5.1 General

Investigations of the economic benefits of some meteorological services are described in the WMO World Weather Watch Planning Report No. 27, "The economic benefits of national Meteorological Services" (1968). As Mason (1968) postulated, benefits of meteorological services to a community are difficult to evaluate in purely financial terms. Nevertheless, it is important to attempt cost/benefit analysis even when the data and the assumptions are not absolute. If we calculate benefit/cost ratios using sensible and conservative terms, we can tolerate even rather large errors in benefit/cost values.

Summaries follow of benefit/cost studies of agrometeorological services in the U.K., France and Hungary.

5.2 In the United Kingdom

Mason (1966, 1968) studied benefits and costs of the agrometeorological service of the U.K. (see also WWW Planning Report No. 17, "Assessing the economic value of a national Meteorological Service" (1967)). Several examples have already been cited:

Hay and milk (item 4.2)	£2 million benefit
Wheat and barley (item 4.2)	£2 million benefit
Potato blight (item 4.7)	£1 million benefit
Sugar beet virus (item 4.7)	£1 million benefit
Animal diseases (item 4.8)	£4 million benefit
Total	£10 million benefit

Additional gains came from weather-sensitive investment decisions on fixed assets such as farm buildings, equipment and machinery. Mason estimated these to be worth several million pounds annually, so he considered total benefit to be much higher than £10 million, probably about £20 million.

The staff and organization provided specifically for agrometeorological work cost about £50 000 per year. To this, Mason added a one-ninetieth share of the cost of the entire meteorological service and estimated total agrometeorological cost at about £80 000 per year.

Figuring benefits to average between £10 million and £20 million and costs to average about £80 000 per year, we may conclude that the benefit/cost ratio is at least 120 : 1 and perhaps twice that.

It may be seen from benefit/cost ratios for other sectors of the economy given by Mason (1966 and 1968) that these ratios are appreciably lower than for agriculture. In aviation, for example, the corresponding ratio is about 10 : 1, and for the power industry about 20 : 1. He estimated the overall benefit/cost ratio of the Meteorological Office to be about 20 : 1.

5.3 In France

Giovanelli (1968) studied benefits and costs of the agrometeorological service of France, some examples are in Chapter 4 of this report.

Giovanelli estimated annual gains due to use of meteorological information and assumed that the gains obtained at certain locations were representative for all of France.

Orchards (total area 815 000 acres)

Two treatments a year avoided			
with a gain of	FF	32	per acre
Anti-frost campaign	FF	160	per acre
Total	FF	192	per acre

Overall gain would be about FF 156 million

Vineyards (total area 3 100 000 acres)

Two treatments a year avoided			
with a gain of	FF	28	per acre
Anti-frost campaign	FF	160	per acre
Choice of wine harvest date	FF	40	per acre
	FF	228	

Overall gain would be about FF 706 million

The total annual gain for orchards and vineyards is thus about FF 862 million. But Giovanelli noted that farms in France are often very small and farmers cannot use regularly the large-scale treatments associated with the gains he calculated. Rather, actual total gain would be only about one quarter of the calculated total, or about FF 216 million. This estimate is probably low, because of other meteorological assistance activities mentioned by Giovanelli, but not considered in the calculations, such as: long-term choices regarding agricultural supplies, manpower and agricultural equipment, and operational activities, either at regional level (irrigation, defence against natural calamities) or locally (choice of crops, varieties and seeds). Gains due to these activities could not be calculated but they appear to be substantial.

Giovanelli estimated costs incurred by the French Meteorological Service in providing its assistance. He attributed four per cent to agriculture and 33 per cent to basic organization structure (network, transmissions, equipment) from which all users benefit. The annual budget was about FF 100 million.

Giovanelli did not estimate the agriculture share of basic service costs. Assuming this share to be about one-ninetieth, as in the U.K., we can estimate that the total cost of services to French agriculture was about FF 4.4 million. The benefit/cost ratio, therefore, would have been at least 49 : 1 and probably much higher. Giovanelli indicated that the overall benefit/cost ratio of the French Meteorological Office was nearly 20 : 1.

5.4 In Hungary

Czelnai, Desi and Szepesi (1970) studied the role of the Hungarian Meteorological Service in the national economy, and calculated the benefit/cost ratios for 11 economic sectors. Significantly, the highest ratio was for agriculture (26.5 : 1). Next were energy production (15.6 : 1) and merchandising (5 : 1). The overall benefit/cost ratio for the Hungarian Meteorological Service was 11.2 : 1.

5.5 Conclusions

For the three countries for which the benefit/cost ratios for agrometeorological services have been determined, ratios were appreciably higher for agriculture than for the meteorological service as a whole. Statistics suggest that meteorological information of comparable cost produces higher economic benefit when applied to agriculture than when applied to other sectors of an economy.

CHAPTER 6

ECONOMIC BENEFITS OF AGROMETEOROLOGICAL INFORMATION AND ADVICE IN DEVELOPING COUNTRIES

6.1 General

Case studies of economic benefits of agrometeorological information and advice described in prior sections are from developed countries - often among the most advanced in the world. Bernard (1968) indicated that the economic role of meteorology in the developing countries is of a radically different character from its role in developed countries. This is also true for the economic role of agrometeorology and for the value of agrometeorological information and advice.

In developed countries, agriculture has already assumed its main lines of operation, so that agrometeorology is often a matter of protection from and fight against weather calamities. Much of the large sum attributed to the economic value of agrometeorological information and advice in developed countries is, in fact, due to losses that have been avoided. In a developing country, the economic role of agrometeorology is primarily to contribute to the country's development by securing the best return from agriculture. The economic benefits of agrometeorology in developing countries are often positive and not merely losses that have been avoided; such benefits can represent important percentages of national income. The value of agrometeorological information and advice, therefore, is relatively much greater in developing countries than in developed countries.

6.2 Examples

A number of examples follow, illustrating economic benefits of agrometeorological information and advice in some developing countries.

Cochemé (1969) proposed that the most important factor in Kenya's extraordinarily successful corn (maize) production in recent years had been the sowing of suitable varieties at the right time of year by fitting the life-span of crops to the length of the rainy season.

Tewungwa (1969) reported that rainfall reliability maps of East Africa have been widely used in determining adaptability of crops in certain areas. Knowledge of the probability of two or more successive months with rainfall below specified limits, for example, helped the successful introduction of tea farming in parts of Kenya. Likewise, it helped to extend the sugar growing area in Kenya and Tanzania, and to determine suitability of areas for growing tobacco. Calculation of confidence limits for rainfall amounts were useful for determining the most suitable dates for planting cotton.

Dagg (1965) matched water requirements of specific crops to specific climates and soils by using meteorological data. The method proved useful for the selection and development of new strains of corn adapted to particular local climates in East Africa.

The WMO publication "Twenty years of WMO assistance" (WMO-No. 338, 1972). describes agrometeorological studies made to select suitable growing areas in Cameroon for best quality and highest production of bananas and pineapples. As a result, the intensive cultivation of appropriate varieties appreciably improved output. The same publication mentions agrometeorological investigations in Ecuador leading to successful introduction of soy-beans in a region where only pastures and tea growing had been considered suitable. It also presents a water requirement study in Sudan. Evaporation data taken at agrometeorological stations in the Gezira clay plains were used together with crop factors to calculate water requirements of different crops and to determine the frequency of irrigation. This helped in planning expansion of potentially irrigable clay plains elsewhere in the Sudan.

With the aid of meteorological information, Egyptians were able to better estimate crop yields and insect infestations, improve crop yields, and increase agricultural exports in fiscal year 1968-1969 over the previous year by about 15 per cent (about 28 million Egyptian pounds). Agrometeorological observations helped find ways to increase mango yields by chemically adjusting flowering periods for a more favourable exploitation of temperatures and humidities. Yields increased about one ton per acre, valued at about 250 Egyptian pounds. Producers irrigate citrus fruits (about 200 000 acres) if forecasts call for heat waves and periods of low humidity. Irrigation before such weather can increase fruit yield by about one ton per acre and is well worth the cost and effort with the extra fruit valued at 50 to 100 Egyptian pounds.

Tewunga (1969) cited work of McCulloch, Pereira, Kerfoot and Goodchild, (1965) who found that the practice of growing tea under shade appreciably reduced yield and also adversely affected tea quality. Tea is an important export crop of East Africa.

"WMO helps the developing countries" (WMO-No. 307, 1971) shows how weather information applied to frost protection of crops in Jordan, especially winter vegetables and bananas, can save US $2 million annually.

Knowledge of the relationship between desert locust movement and weather conditions found by Rainey (1963) has been useful in planning locust control operations in East Africa, with considerable economic benefits to susceptible African countries. According to "Twenty years of WMO assistance" (WMO-No. 338, 1972), knowledge of this relationship was also used to establish a service to warn of infestations of army worm, another major African pest. The same publication describes a tailor-made radar-based forecast system for cotton pest control in Tanzania and suggests a 7 : 1 benefit/cost ratio. And in Ecuador, banana producers use meteorological and micrometeorological observations to schedule pest-and disease-control measures.

The cotton leaf worm is the most important cotton pest in Egypt. Researchers developed a formula to predict the approximate rate of insect infestation during summer from knowledge of average air temperatures between 11 February and 10 April. The method anticipates outbreaks early enough to allow time to prepare for combatting the pest, encourages rational purchase of imported insecticides, and promotes increased yield.

6.3 Conclusions

The value of agrometeorological information and advice can be relatively much greater to developing countries than to developed countries. Although few case studies of meteorological benefits to developing-country agriculture include values, a large economic benefit is generally obvious. For a more accurate picture, however, there is an urgent need for a study of benefit/cost relationships and an assessment of agrometeorological services in these countries.

CHAPTER 7

POTENTIAL ECONOMIC GAIN IN AGRICULTURAL INDUSTRIES FROM IMPROVED METEOROLOGICAL INFORMATION

7.1 General

Agriculture and its allied industries know the value of information on weather and climate. After all, man began to take weather and climate into account in his earliest efforts to cultivate crops and husband animals. Obviously, the agricultural community, and indeed all people of the world, would benefit from improved weather forecasts and climatological information. Satellites and new data-processing technology are among the means of achieving such improvement, improvement that can be translated into more reliable and effective production and distribution systems.

7.2 Selected cases

Thompson (1966) referred to studies of weather forecasts for drying and curing raisins (Kolb and Rapp, 1962, and Lave, 1963). These indicated improved methods would increase the value of California's San Joaquin Valley raisin crop by about US $10 million. Thompson found no demand, however, for further increase in production; rather, such an increase could lower both price and total value. Thompson suggested that the area devoted to raisin culture should be reduced. If the released area were used for growing crops in greater demand, the annual gain might range from US $22 million to US $45 million.

In the Griffith area of New South Wales (Australia), Gibbs (1968) determined that two-to three-day warnings of heavy rains would save about A $1 million annually through harvesting of tomatoes and grapes in advance. He also valued at about A $100 000 per year the potential benefit of a more accurate determination of Jonathan apple maturity to enhance keeping quality in cold storage.

Lave (1963) believed forecasts of rain made three weeks in advance would benefit table-grape growers in the San Joaquin Valley about US $91 per acre annually or $20 million in all.

Gibbs (1968) indicated that 30-day forecasts for rain and relative humidity could promote orderly harvest of peaches and reduce losses from brown rot in New South Wales. Potential savings would be about A $1 million annually. Similar forecasts could cut grape losses from downy mildew by about A $5 to 6 million in severe outbreak years.

7.3 Potential economic gains to agriculture in general

Thompson (1966) examined several studies and estimated that potential improvement in weather analysis and forecasts leading to predictions several days in advance could save about 15 to 20 per cent of avoidable losses in the U.S.A. He applied this percentage to 1961 crop losses caused by various weather elements including drought, excess moisture, hail, cold weather, wind and floods.

Total losses were about US $1 200 million and estimated potential savings about US $200 million. Thompson based this figure on "order-of-magnitude" estimates of crop losses and suggested a need for more precise figures obtained from more complete and reliable data. His estimate is probably exaggerated because the study assumed that losses due to different weather elements were avoidable. It is difficult to estimate what percent of total loss is avoidable. If 80 per cent is an appropriate figure, potential saving would be about US $160 million based on agricultural contribution to the national income of US $22 000 million. Such a saving would depend on perfect forecasts made several days in advance. Since forecasts are not perfect, the saving would be somewhat lower.

Thompson (1968) estimated total potential economic gain for different sectors of the U.S. economy and assumed utopian improvements in weather forecasts for periods of 24 to 36 hours in advance. As a result of his work in 1962 and 1968, he considered the mean economic gain, in units of potential loss, from scientific advances and operational improvements to each, to be about five per cent of "order-of-magnitude" estimates of total agricultural weather losses in the U.S.A. He also estimated that short-term protective measures could be taken to halve losses, which would result in a total annual potential economic gain of about US $500 million. Half of that gain would be from scientific advances or operational improvements. If we apply the same methods and assumptions used by Thompson to estimate agricultural weather losses at about US $1 200 million, the annual potential gain would be about US $60 million. Potential gain for agriculture would be about 12 per cent of the gain for all sectors of the economy. It is also about 40 per cent of the estimated potential gain for agriculture in the U.S.A. from improved meteorological information provided several days in advance.

Thompson (1966) indicated that, although the contribution of agriculture to the national income of the U.S.A. is much lower than that of manufacturing or merchandising, agriculture ranked highest among all activities in potential economic benefits to be gained from improved meteorological information. That is because agriculture is more sensitive to weather than other activities.

Mason (1966) believed that reliable forecasts for a week and for a season would bring great benefit to agriculture in the United Kingdom. Forecasts covering a week are especially important because most decisions regarding major farm operations, such as ploughing, sowing, irrigation and harvesting, are made on this time scale. He estimated potential value of such forecasts to be at least £50 million annually, where annual value of agricultural production is about £2 000 million. Mason did not estimate potential value of seasonal forecasts, but he indicated that they would be very useful for making plans and decisions on crop selection, farm buildings and machinery, pest control, irrigation, and sundry other matters.

Mason stressed the importance of improving daily forecasts used in planning day-to-day activities. Many decisions are based on daily forecasts and a small improvement in accuracy or detail would produce considerable benefit.

Gibbs (1968) estimated that the potential economic gain to Australian agriculture would be about A $50 million annually from improved meteorological information and especially from extended-period forecasts. Accurate forecasts six to twelve months ahead would be useful in reducing drought losses and would be worth tens of millions of Australian dollars per year. Although agriculture contributed only 15 per cent to the total national income, it ranked highest in potential economic benefit from improved meteorological information, again due to the extreme sensitivity of agriculture to weather.

7.4 Benefits from satellite observing and forecasting systems

A Stanford University study of a proposed weather satellite system (1966) concluded that annual benefit to world agriculture ranked highest among the different economic sectors. Agriculture claimed about US $6 billion out of US $17 billion of the total benefit. Though based on incomplete data, these values indicate that appreciable improvement in meteorological information would lead to large benefits to international agriculture. Of course, satellite systems have advanced considerably since the Stanford study, undergoing a wealth of improvements and innovations leading to better weather observation and forecasts and increased application of remotely-sensed data to agriculture.

Satellites facilitate monitoring of potentially damaging storms (cyclones, for example) to the benefit of early-warning systems. We have gained time to take protective or evasive measures. But satellites and their telecommunication and data systems provide much more. Today we are better able:

- To locate the important Intertropical Convergence Zone (ITCZ) and thereby interpret weather activity in monsoon regions;

- To observe the position and strength of atmospheric fronts and anticipate their movement and influence;

- To locate ocean currents and judge their weather impact;

- To measure sea surface temperature, a major step towards better extended-term weather forecasts;

- To observe snow and ice cover and relate it to agriculture, transportation and hydrology;

- To observe water storage and flow to assess flood potential and water availability for energy, irrigation and transportation.

Yet from an agricultural point of view there are other important aspects of satellites to be researched, tested and applied. Some potential applications are:

- To complement and supplement ground observations;

- To determine area and intensity of precipitation;

- To measure land surface temperatures;
- To measure effective solar radiation;
- To estimate soil moisture and snow depth (water content);
- To estimate wind speed and direction;
- To detect special phenomena such as cloudbursts, violent thunderstorms, hail, and rapid, extreme temperature changes.

Work progresses on satellite-data application to such purely agricultural topics as crop indentification, acreage estimates for major crops, determination of crop development and condition, assessment of pest infestation and damage, harvest rates, yield and production forecasts.

The value? Unknown. But certainly information derived from satellites offers mankind a great opportunity to combat hunger, disease, and misery in the world, through improved weather knowledge and forecasts.

7.5 Conclusions

Agriculture stands to benefit more than most other sectors of national economies from improved meteorological information. Gain resulting from operational improvements is largely attainable within the present state of meteorological knowledge, while that to be derived from scientific advances lies in the future. Thus without waiting for scientific improvements considerable benefits can be realized, especially through close collaboration between agriculturalists and meteorologists.

Substantial gains could be achieved from significant improvements in forecast accuracy and by extending forecast range. And the potential benefits warrant a considerable effort to reach these objectives.

CHAPTER 8

CONCLUSIONS

We have attempted to identify applications and economic benefits to agriculture from both present and potential improved agrometeorological information and advice. We have also tried to give monetary values to these benefits. Research has demonstrated that applied agrometeorology can produce considerable benefit to national economies, strengthening the vulnerable agricultural sector.

Yet it is important to bear in mind the difficulty of assessing benefit. J. C. Thompson, often quoted in this note, rightly expressed concern about assigning values without a thorough look at the whole complex economic situation. For example, we cannot automatically translate increased production into increased value. In agriculture, production increases usually mean price decreases, at least at the state or national level. Increased quantity available at a lower price often means lower profits for producers and sometimes for distributors and retailers as well.

Increased supplies at lower prices are, of course, beneficial to consumers. But that situation is not always bad for producers. Continuity of supply over a reasonable price-range is usually necessary to maintain consumer loyalty to a product. High prices drive consumers to lower-priced substitute products, which they do not always abandon quickly. Unfortunately, in cases of extreme poverty, high prices can involve hunger for consumers.

Low prices, on the other hand, tend to induce producers to cultivate better-paying crops, to make, of necessity, wiser planting or processing choices. Such changes restore a measure of order to supply/demand relationships. As Thompson (1966) suggests, why grow more raisins if there is little consumer demand and the extra raisins lower prices and lead the producer into bankruptcy? Wiser land use could very well be the greatest benefit from applied agrometeorology.

Much land is devoted to a particular crop to fill a void left by weather-related loss and damage occurring during production, harvest, transportation and storage. Such use is wasteful. That land and other resources could be used more efficiently to fill other needs. These needs might be food, fibre, timber or recreation, but the important point is for land use to suit the land, to enhance the land rather than degrade it.

A major objective of this report is to emphasize the importance of agrometeorological information and advice to production, harvest, transport and storage of agricultural products, as well as the need to apply our national and international resources to develop and use agrometeorology in order to realize benefits.

Already there are large reservoirs of weather and agricultural information. Likewise, there is a bank of knowledge on what to do with this information. Research continues to expand and improve them. Yet agrometeorology cannot be taken for granted. Agriculture is man's attempt to order the interrelationships of weather, soils, plant materials and animal life. Weather and each of the other factors are themselves collections of interacting elements – though weather seems the most capricious. The better we anticipate weather, exploit our knowledge of it, disseminate that knowledge, and apply what we know to managing our resources, the better we all will live.

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REFERENCES

Anderson, L. G., 1973: The economics of extended-term weather forecasting. Monthly Weather Review, 101, No. 2, pp. 115-125.

Asopa, V. N., Guise, J. W. and Swanson, E. R., 1973: Evaluation of returns from irrigation of corn in a sub-humid climate. Agric. Meteorol., 11, pp. 65-78.

Baier, W., 1972: An agroclimatic probability study of the economics of fallow-seeded and continuous spring wheat in southern Saskatchewan. Agric. Meteorol., 9, pp. 305-321.

Baier, W. and Robertson, G. W., 1966: A new versatile soil moisture budget. Can. J. Plant Sci., 46, pp. 299-315.

Berggren, R., 1972: Final report on economic benefits of climatological services. Submitted to CoSAMC, WMO.

Berry, I. L., Shanklin, M. D. and Johnson, H. D., 1964: Dairy shelter design based on milk production decline as affected by temperature and humidity. Trans. of the Amer. Soc. of Agric. Engrs., 7 (3), pp. 329-331.

Borgman, E. and Brooker, D. B., 1961: The weather and hay making in Missouri, Univ. of Missouri Agr. Exp. Sta. Bull.,77, 7 pp.

Brooker, D. B. and McQuigg, J. D., 1960: Analysis of weather data pertinent to grain drying. Trans. of the Amer. Soc. of Agr. Engr., 3, pp. 116-119.

Brooker, D. B. and McQuigg, J. D., 1963: Weather analysis for crop drying. Univ. of Missouri Agr. Exp. Sta. Bull., 837.

Brier, G. W., 1950: Verification of forecasts expressed in terms of probability. Monthly Weather Review, 78, pp. 1-3.

Cochemé, J., 1969: Agricultural meteorology and the role of meteorological services in economic development in Africa. Proceedings of the ECA Seminar, Ibadan, Nigeria, September 1968, WMO, Geneva, pp. 69-76.

Czelnai, R., Desi, F. and Szepesi, D., 1970: On the economical efficiency of meteorological activities. Idojaras, 74, pp. 484-96.

Dagg, M., 1965: E. Africa Agriculture and Forestry Journal, 30, No. 3.

Dessens, I., 1968: Experience de suppression de la grêle dans le sud-ouest de la France. Proc. Int. Conf. Cloud Physics, Toronto, 1967

Epstein, E. S., 1962: A Bayesian approach to decision-making in applied meteorology. J. Appl. Meteor., 1, pp. 169-77.

Ewalt, R. E., Wiersma, D. and Miller, W. L., 1973: Operational value of weather information in relation to soil management characteristics. Agron. J., 65, pp. 437-39.

Fisher, R. A., 1924: The influence of rainfall distribution on the yield of wheat at Rothamsted. Phil. Trans. R. Soc., Ser. B., 21, pp. 389-412.

Gibbs, W. J., 1968: Benefits of meteorological services in Australia. In WWW Planning Report, No. 27, WMO, Geneva, pp. 1-8.

Giovanelli, J. L., 1968: The economic advantages of the French National Meteorological Service. In WWW Planning Report, No. 27, WMO, Geneva, pp. 9-18.

Glahn, H. R., 1964: The use of decision theory in meteorology with an application to aviation weather. Monthly Weather Review, 92, No. 9.

Gleeson, T. A., 1960: A prediction and decision method for applied meteorology and climatology based partly on the theory of games. J. Meteor., 17, pp. 116-21.

Gringorten, I. I., 1959: Probability estimates in relation to operational decisions. J. Met., 16, No. 6. pp. 663-71.

Hahn, G. L. and McQuigg, J. D., 1967: Expected production losses for lactating Holstein dairy cows as a basis for rational planning of shelters. ASAE paper, Mo-67-107.

Hahn, LeRoy, McQuigg, J. D. and Osburn, D. D., 1972: Summer environmental modification for dairy cow housing in Missouri. Paper presented at the 1972 Annual Meeting of Amer. Agr. Engr., St. Joseph, Michigan.

Hahn, LeRoy and Osburn, D. D., 1969: Feasibility of summer environmental control for dairy cattle based on expected production losses. Trans. of the Amer. Soc. of Agric. Engrs., 12(4), pp. 448-51.

Hahn, LeRoy, Osburn, D. D. and McQuigg, J. D., 1971: Rational selection of livestock environments. Proceedings, Vth International Symposium of Zootechny, 1971, Milan, pp. 737-745.

Hobbs, P. V., 1968: The scientific basis, techniques, and results of cloud modification. In: Fleagle, R. G., ed., 1968: Weather Modification: Science and public policy, Univ. of Washington Press, Seattle, pp. 30-42.

Hogg, W. H., 1966: Meteorological factors in early production. Memo. No. 9, Univ. Coll. of Wales, pp. 16-29.

Hogg, W. H., 1970: Basic frost. Irrigation and degree-day data for planning purposes. Weather Economic, Pergamon Press, pp. 27-49.

Jensen, M. E., Robb, D. C. N. and Franzoy, C. E., 1969: Scheduling irrigation using climate-crop-soil data. Paper pres. at Nat. Conf. on Water Res. Eng., ASCE, Feb. 1969, 21 pp.

Jorgensen, D. L., 1949: An objective method of forecasting rain in central California during the raisin drying season. Monthly Weather Review, 77, pp. 31-46.

Kolb, L. L. and Rapp, R. R., 1962: The utility of weather forecasts to the raisin industry. J. Appl. Meteor., 1, pp. 8-12.

Lahane, J. J. and Staple, W. J., 1965: Influence of soil texture, depth of soil moisture storage, and rainfall distribution of wheat yields in southwestern Saskatchewan. Can. J. Soil Sci., 45, pp. 207-219.

Lave, L. B., 1963: The value of better weather information to the raisin industry Econometrica, 31, No. 1-2.

Lomas, J., 1972: Economic significance of dry-land farming in the arid northern Negev of Israel. Agric. Meteorol., 10, pp. 383-392.

Mackenzie, J. G. 1968: Economics of grain-fallow rotations and fertilizer use in the Prairie provinces. Can. Dept. Agr. Econ., 39 pp.

Mason, B. J., 1966: The role of meteorology in the national economy. Weather, 21, pp. 382-93.

Mason, B. J., 1968: The economic value of meteorological services in the United Kingdom. In WWW Planning Report, No. 27, WMO, Geneva, pp. 19-24.

Mannder, W. J., 1970: The value of the weather. Methuen & Co. Ltd., 388 pp.

McCulloch, J. S. G., Pereira, H. C., Kerfoot, O. and Goodchild, N. A., 1965: Effect of shade trees on tea yields, Agric. Meteorol., 2, (G), pp. 385-399

McQuigg, J. D., 1965: Foreseeing the future. Forecasts and Decisions, Chapter 12, Meteorological monographs, 6, No. 28

McQuigg, J. D., 1968: A review of problems, progress and opportunities in the use of weather information in agricultural management. Proceedings of the Reading Symposium, UNESCO, 1968.

McQuigg, J. D. and Calvert, O. H., 1966: Influence of soil temperatures on the emergence and initial growth of upland cotton. Agric. Meteorol., 3, pp. 179-85.

McQuigg, J. D., Calvert, O. H. and Decker, W. L., 1965: Using weather information to cut the cost of getting a good stand of cotton in southeast Missouri. University of Missouri College of Agriculture, Bull., 835.

McQuigg, J. D. and Doll, J. P., 1961: Weather variability and economic analysis. Univ. of Missouri Agr. Exp. Sta. Bull.,771.

McQuigg, J. D. and Thompson, R. G., 1966: The economic value of improved methods of translating weather information into operational terms. Monthly Weather Review, 94, No. 2, pp. 83-87.

Miller, R. G., 1962: Statistical prediction by discriminant analysis. Meteor. Monogr., 4, No. 25, 54 pp.

Murphy, A. H., 1966: A note on the utility of probabilistic predictions and the probability score in the cost/loss ratio decision situation. J. Appl. Meteor., 5, pp. 534-37.

Murphy, A. H., 1969a: Measures of the utility of probabilistic predictions in cost/loss ratio decision situation in which knowledge of the cost/loss ratios is incomplete. J. Appl. Meteor., 8, pp. 863-873.

Murphy, A. H., 1969b: On expected utility measures in cost/loss ratio decision situations. J. Appl. Meteor., 8, pp. 989-91.

Nelson R. R. and Winter, S. G., Jr., 1960: Weather information and economic decisions, a preliminary report. Rand Report prepared for National Aeronautics and Space Administration, (RM - 2620 - NASA).

Nelson, R. R. and Winter, S. G. Jr., 1964: A case study in the economics of information and co-ordination of the weather forecasting system. Quart. J. of Economics, 78, No. 3, Harvard University, Cambridge, Mass. pp. 420-441.

Nix, J. S. and Prickett, C. N., 1961: Farm crops irrigation, the economic aspects. Cambridge Univ., School of Agriculture, Farm Econ. Branch Rep., No. 55 p. 44.

Rainey, R. C., 1963: Meteorology and the migration of desert locusts. WMO Technical Note, No. 54, WMO, Geneva, 117 pp.

Roten, M. and Primault, B., 1964: Recherches microclimatiques sur la Vallée du Rhone en Valais. Gessler, Sion, 208 pp.

Stanford University, 1966: SPINMAP, Stanford Proposal for an international network for meteorological analysis and prediction - summary report. Stanford University, Palo Alto, Calif., 31 May 1966.

Stauber, M. S., Zuber, M. S. and Decker, W. L., 1968: Estimation of the tasseling date of corn. Agron. J., 60, pp. 432-34.

Sussenberger, E., 1968: Economic benefits of the meteorological service of the Federal Republic of Germany. In WWW Planning Report, No. 27, WMO, Geneva, pp. 51-53.

Tewungwa, S., 1969: Some contributions of meteorology to the economic development of East Africa. *Proceedings of the ECA Seminar, Ibadan, Nigeria, September 1968*, WMO, Geneva, pp. 36-44.

Thompson, J. C., 1952: On the operational deficiencies in categorical weather forecasts. *Bull. Amer. Met. Soc*., 33, pp. 223-226.

Thompson, J. C., 1962: Economic gains from scientific advances and operational improvements in meteorological prediction. *J. Appl. Meteor*., 1, pp. 13-17.

Thompson, J. C., 1966: The potential economic associated values of the World Weather Watch. *WWW Planning Report*, No. 4, WMO, Geneva, 35 pp.

Thompson, J. C., 1968: Potential economic benefits from improvements in weather information. In *WWW Planning Report*, No. 27, WMO, Geneva, pp. 41-50.

Thompson, J. C. and Brier, G. W., 1955: The economic utility of weather forecasts. *Monthly Weather Review*, 83, pp. 249-254.

Wagonner, P. E., 1965: Prologue to agricultural meteorology. *Meteorological Monographs*, 6(28), iii-vii, Amer. Meteor. Soc., Boston, Mass.

Winter, E. J. and Blackwell, F. L. C., 1963: Irrigation of potatoes. *13th Ann. Rep*., Nat. Vegetable Res. Station.

World Meteorological Organization, 1967: Assessing the economic value of a national Meteorological Service. *WWW Planning Report*, No. 17, WMO, Geneva, 14 pp.

World Meteorological Organization, 1968: The economic benefits of national Meteorological Services, *WWW Planning Report*, No. 27, WMO, Geneva, 56 pp.

World Meteorological Organization, 1971: *WMO helps the developing countries*. WMO-No. 307, WMO, Geneva, 86 pp.

World Meteorological Organization, 1972: *Twenty years of WMO assistance*. WMO-No. 338, WMO, Geneva, 188 pp.

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