Agronomy & Water

BACKGROUND PAPERS

AN EVALUATION OF DRIP IRRIGATION FOR COTTON PRODUCTION

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A research project comparing drip irrigation with the standard furrow system started in the 1983/84 season at Narrabri Agricultural Research Station. Drip irrigation has become popular in regions with low or expensive water supply, especially Israel, where efficient use of irrigation water is important. The principle is to have a supply of water provided in pipelines within the crop. Thus water is supplied in small amounts daily, rather than large amounts at infrequent intervals as is the case with furrow irrigation.

The aim of the research project is to directly compare standard furrow irrigation with two types of drip irrigation (above and below ground drippers) in one experiment. Crop and soil parameters will be monitored so that the reasons for any yield differences can be precisely established.

There have been drip irrigated cotton crops in the Namoi and St. George areas for the past two seasons. However, furrow and drip irrigation have not yet been compared in the same field. Precise yield comparisons between furrow and drip systems are essential for economic assessment, since the cost of the pump, filters and supply lines for the drip system means that about 2 extra bales of cotton per hectare per year are required to pay for the initial outlay.

The potential benefits of drip irrigation compared to furrow include:

1. More efficient use of water - especially for a drip irrigation system fed directly from a bore where there would be no losses from supply channel, head ditch or tailwater. This improved water efficiency is important since there are often shortages of irrigation water in many of the dams supplying the cotton areas.
2. Less waterlogging following irrigation or rain.
3. More precise control over the application of water and fertiliser.
4. The application of systemic insecticides through the irrigation system.
5. New developments on steep country or on soil of variable texture can be utilised for cotton production.

As a consequence of these benefits, there have been reports from Arizona and Israel of 2.5 bale/ha advantages of drip irrigation over other irrigation methods. Theoretical yield advantages in Australia come from avoiding waterlogging. Other than providing an unbiased direct comparison between the different systems, this experiment will aid a number of research programs. The drip irrigation facility will contribute greatly to the study of waterlogging, nutrition, water relations, physiology of fruiting, pest management and genotype evaluation. The experiment will continue for at least three seasons.

Results 1983/84

Planting in mid October followed extensive rain during winter and early spring, so there were no differences in establishment between drip and furrow irrigation systems.

Further heavy rain in January created extensive waterlogging in all treatments and delayed the application of nitrogen to drip irrigation treatments. This delay was probably an advantage in the season as it turned out: the sustained cloudy weather affected tall rank crops the most by delaying their boll setting.

The measured pattern of nitrogen uptake in the experiment is shown in Figure 1.

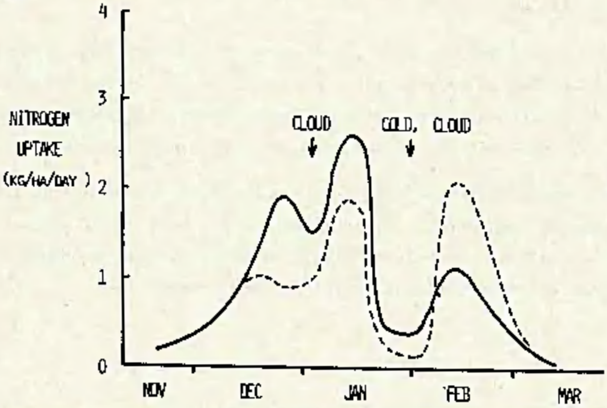

Figure 1. Measured nitrogen uptake from furrow irrigated (-) and drip irrigated (---) cotton in 1983/84. N applied to drip treatments in Dec and Jan.

The unfavourable weather in January severely restricted nitrogen uptake in all treatments. As a result, nitrogen uptake continued late in the season and created some undesirable, though manageable top growth. An ideal pattern of nitrogen uptake during the season has been presented in another article. It was aimed to use this ideal pattern in the 1983/84 season to schedule nitrogen applications to drip irrigation treatments. Continued rain interfered with this schedule, but it appears to be a worthwhile approach.

The yield of each treatment in the 1983/84 season is shown in the following table:

Treatment	Lint yield kg/ha		
	Pick 1	Pick 2	Total
Surface drip - Netafim 'Gadash'	1587	83	1670
Buried drip - RIS 'Biwall'	1539	129	1668
Furrow irrigation	1533	87	1620

As can be seen, method of irrigation in this wet season has influenced yield very little. The small non significant differences in yield are more likely due to the different pattern of nitrogen uptake.

Comparison between above and below ground drip systems

1. An above ground drip system is 'portable', i.e. a rotation can be practised, using the same equipment. Early season irrigation can be less effective, as some of the water applied to the furrow is lost through evaporation. Inter-row cultivation is difficult, as the drip lines in the furrow interfere with traffic.

2. A buried drip system is not portable and permanent beds/minimum tillage cultivation is necessary for the life of the system. However inter-row cultivation is not impaired. Early season irrigation (from sowing to January) is more effective than with above ground drippers.

Given these differences, the best system would depend on the particular circumstances at each site; e.g. diseases, weeds, soil type, surface conditions etc. It may be that a mixture of above and below ground drippers on some farms would be the most efficient compromise.

Review of potential benefits

1. **Water use efficiency.** There are negligible losses of water from within a drip irrigation system - probably about5%. Losses from furrow irrigation systems are usually 20-30%.

2. **Waterlogging.** There is a 50/50 chance of drip or furrow irrigation being more waterlogged by heavy rainfall: If it rains just prior to when a furrow irrigation is due, it will be more capable of accepting the water before becoming waterlogged. The waterlogging that occurs after furrow irrigation is avoided by drip irrigation.

3. **Fertiliser.** There are potential benefits in fertiliser economy with drip irrigation. Savings can be made on nitrogen fertiliser costs by only applying nitrogen when it is required. These savings would not pay for the cost of a drip irrigation system. Addition of higher rates of fertiliser during the season can be applied easily - if required.

4. **Yield.** A wet environment does not justify the use of drip irrigation. The benefits of drip irrigation in a dry season are yet to be evaluated in this project before firm recommendations can be made, however it seems that advantages in yield in excess of 2 bales/ha are required in dry seasons to make up for the lack of advantage in wet seasons.

IRRIGATION DEMONSTRATIONS - EMERALD 1982/83

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Cotton yields in the Emerald Irrigation Area (E.I.A.) have fluctuated considerably during the last five season. Following an average yield in excess of 4.5 bales/ha in 1980, district average yields fell to about 3.3 bales per hectare in 1981 and 1982. Irrigation management appeared to be part of the problem so irrigation demonstration/monitoring sites were established throughout the district. These sites were aimed at demonstrating the importance of irrigation management and evaluating two methods of irrigation scheduling; the simple water balance approach and the neutron moisture meter (N.M.M.) approach. Careful monitoring of crop development helped assess crop growth as the season progressed and highlighted the effects of the irrigation treatments.

Four sites in the district were chosen as demonstration sites. These sites were located so that farmers from the various socio/geographic groups in the district had ready access to a demonstration area. At each site, two irrigation treatments were imposed. One area was frequently irrigated; irrigated at an 80 mm* deficit, while the other area was infrequently irrigated; irrigated at a 120 mm* deficit. At each site, changes in soil water content were followed with the neutron moisture meter. Plant height and fruit production were regularly measured.

At one of the sites, the Walter site, a third irrigation strategy was imposed; apply the first irrigation at first flowers. This had become commercial practice in the district. Detailed information will be presented from the Walter site. The other three sites produced similar results.

Crop Yields.

Table 1 shows the yields measured at the Walter site. These yields were measured after commercial ginning.

* This deficit is calculated using a simple water balance approach. See Yule and Keefer paper for details.

Table 1. Yields from the Walter Site (1982/83.)

Irrigation Deficit	Number of Irrigations	Yield bales/ha.
80 mm	6	7.5
120 mm	3	6.6
Delayed *	4	5.5

* This treatment received its first irrigation when flowers first appeared. Subsequently, the treatment was irrigated at an 80 mm deficit.

Crop yields were highest in the most frequently irrigated treatment. The "delayed" treatment produced the poorest yields despite the application of four irrigations instead of the three irrigations applied to the 120 mm treatment.

Crop Development.

Plant height measurements indicate how growth was affected by irrigation treatments. Figure 1 shows the development of plant height at the Walter site.

Figure 2 shows the development pattern for squares for the three irrigation treatments. Square production was greatest in the 80 mm treatment throughout most of the growing season. Early in the growing season, the 120 mm treatment produced slightly fewer squares than the 80 mm treatment, but square production for the "delayed" treatment was severely reduced throughout December. Later in the season, after mid January, the "delayed" treatment produced more squares than either of the other treatments. Apparently, the early drought stress reduced square production and the plants attempted to compensate later in the season.

Flower production patterns shown in Figure 3 reflect the square production patterns in Figure 2. Again, the 80 mm treatment produced more flowers than either the 120 mm treatment or the "delayed" treatment.

Compared with the 120 mm treatment, flower production was reduced in the "delayed" treatment throughout December and most of January. However, late flower production in mid-February was greater in the "delayed" treatment. By delaying irrigation until first flowers, the rate of early flower production was reduced but late season flower production increased.

Clearly, at this site, the early (prior to flowering) irrigations, were critical in setting yield potential. Delay in the development of squares, flowers and bolls resulted from an early stress and yield was reduced accordingly. Although the plants attempted to compensate for the poor early production, full yield potential was not realised.

Scheduling Irrigations.

Table 2 shows a comparison between the water balance method of scheduling irrigations and the method using the neutron moisture meter. These comparisons are based on the scheduled irrigation deficit for the water balance model and the average refill point measured with the neutron meter. The calibration used for the neutron meter is the one used commercially.

Table 2. Comparison of water balance model and neutron moisture meter for irrigation scheduling at the Walter site.

Treatment	Irrigation	Predicted Irrigation Date*		Actual Irrig. Date
		MODEL	NMM	
80 mm Deficit	1	10/11	not installed	11/11
	2	28/11 (-1)	28/11 (-1)	29/11
	3	17/12 (0)	15/12 (-2)	17/12
	4	30/12 (+3)	1/1 (+3)	29/12
	5	13/1 (+1)	14/1 (+2)	12/1
	6	25/1 (0)	27/1 (+2)	25/1
120 mm deficit	1	18/11	not installed	18/11
	2	15/12 (+1)	14/12 (0)	14/12
	3	16/1 (-2)	19/1 (+1)	18/1
Delayed until first flowers then 80 mm Deficit	1	First Flowers		10/12
	2	23/12 (-6)	24/12 (-5)	29/12
	3	13/1 (+)	12/1 (0)	12/1
	4	25/1 (0)	25/1 (0)	25/1

* difference between actual and predicted shown in parentheses.

Close agreement is shown between the scheduling methods. The differences between actual irrigation date and the predicted irrigation date is shown in parenthesis. The largest discrepancy between the NMM prediction and the water balance model prediction was three days. This occurred at the third irrigation of the 120 mm deficit treatment. This discrepancy is small in relation to field variation and demonstrates that both methods can adeauately schedule irrigation. Similar agreement between scheduling methods was shown at the other sites.

Comparing Sites.

Time taken for the various phases of fruit development is shown in Figure 4. Both of the October planted crops took about 60 days to reach first flowers while the November planted crops flowered sooner, in 50 - 55 days. Yields were lower for the later crops. Rapid development through the fruiting phases with later planting may account for some reduced yield potential. Usually, more rapid fruit development results from higher temperatures and compared with other cotton growing areas in Australia, early in the season, Emerald experiences relatively hot weather. Observations suggest that October planted crops have a higher yield potential than later planted crops at Emerald.

Conclusions.

1. Delaying the first post planting irrigation until flowering can seriously delay fruit set and can reduce yields substantially.

2. Timing of irrigations is important. Although the more frequent irrigation strategy generally produced greater yields at these demonstration/monitoring sites in 1982/83, few irrigations produced satisfactory yields, provided these irrigations were applied at the correct time.

3. Scheduling irrigations is an important aspect of crop management. Either a water balance model or the NMM can be used to schedule irrigations. For best results, these methods should be used in conjunction with one another.

4. Plantings after mid November at Emerald may have reduced yield potential.

Acknowledgements.

I am grateful to the farmers who willingly co-operated in these demonstrations, to the Cotton Research Committee for providing funds and to Russell Parker for his assistance in the field.

Figure 1. Development of Plant Height WALTER SITE

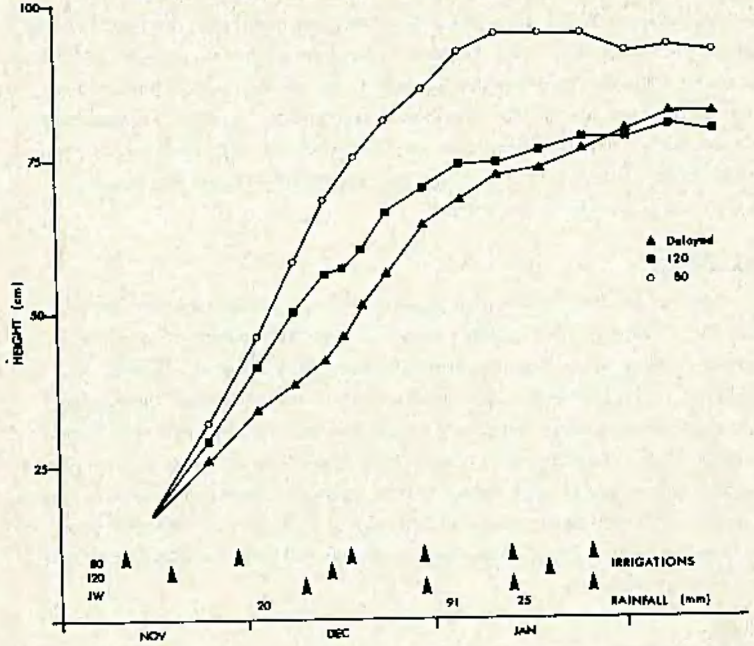


Figure 2. Square Production WALTER SITE

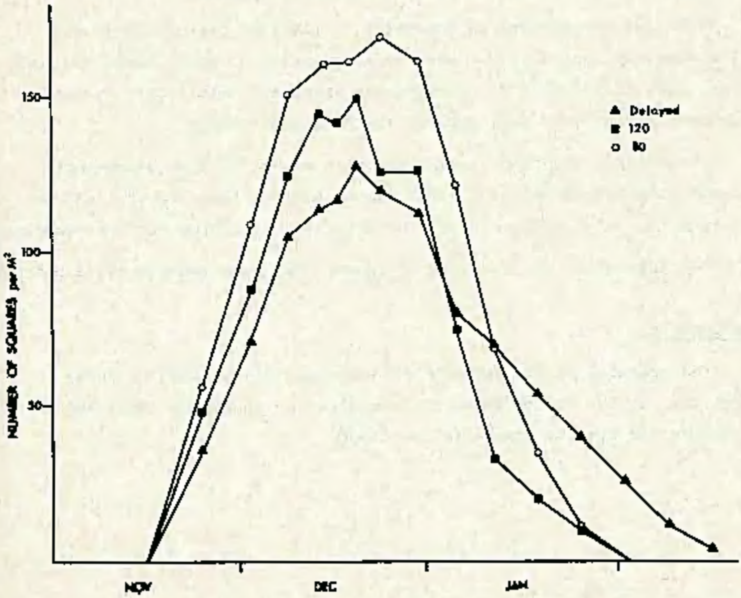


Figure 3. Flower and Green Boll Production WALTER SITE

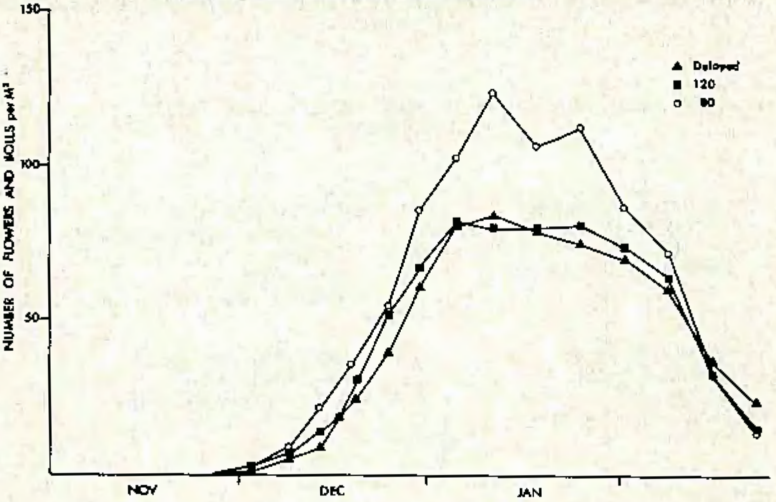
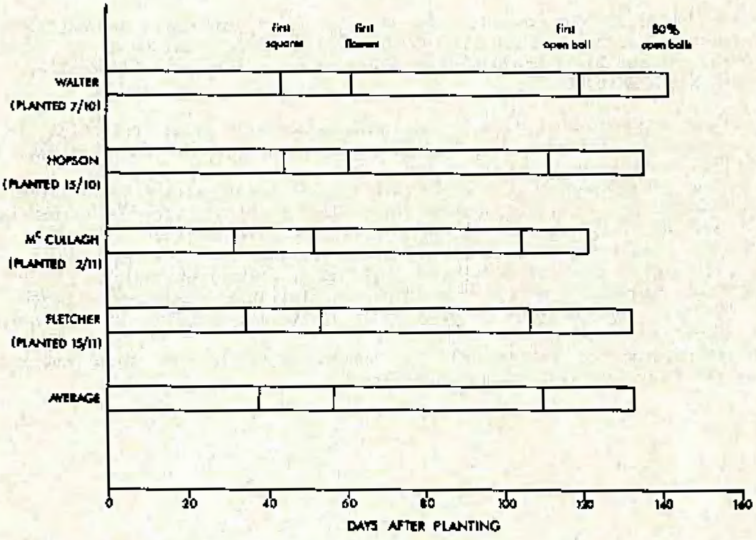


Figure 4. Comparison of Plant Fruiting Behaviour at Four Sites



THE BENEFITS OF ON - FARM SOIL WATER MONITORING AND IRRIGATION SCHEDULING FOR IMPROVED WATER MANAGEMENT - CASE STUDIES FROM COTTON FARMS IN AUSTRALIA.

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ABSTRACT

On farm soil water monitoring to aid in irrigation scheduling has rapidly expanded in the past three years. The development of a user friendly package for soil water monitoring using the Neutron Probe has allowed irrigation scheduling to be carried out on an objective basis and provided quantitative data to solve water related field production problems. The solution of these field production problems can often substantially improve farm income with little change in inputs.

The case studies discussed illustrate the use of soil water monitoring to schedule irrigations for high yields and to develop databases to solve water related field production problems by coton farmers in Australia. The case studies are:

1. The evaluation of drip irrigation compared with flood irrigation in terms of water savings and yield improvements for cotton at Wee Waa, New South Wales.
2. The determination of a whole farm irrigation efficiency by studying channel and tailwater soakage losses for use to aid water ordering in periods of limited allocation at Moree, New South Wales.
3. The quantification of a through drainage problem with furrow irrigation on an alluvial soil at Biloela, Central Queensland.
4. Root pruning or cotton from interrow cultivation resulting in sudden wilting and decline in daily water use of cotton crops at Emerald, Central Queensland.
5. Scheduling of irrigations on compacted soils for high cotton yields at Emerald, Central Queensland.

INTRODUCTION

On farm, soil water monitoring to aid in irrigation scheduling has expanded rapidly in the past three years. The development of a user friendly package for soil water monitoring using the neutron probe has enabled farmers and consultants to obtain quantitative data on crop water use and root extraction patterns. This has allowed irrigation scheduling to be carried out on an objective basis and for water related field production problems to be solved. The solution of these field production problems can often substantially improve farm income with little change in inputs.

The following case studies illustrate typical water related problems encountered and solved by farmers and fieldmen using this water management package.

1. THE EVALUATION OF DRIP IRRIGATION

Drip irrigation is a relatively new technology to field crop production in Australia and as well, experience of its application on cracking clay soils is limited internationally.

There has been tremendous interest in drip irrigation by leading cotton growers in the Namoi Valley in the past three years. For these cotton growers drip irrigation offers the potential to increase yields and to reduce crop water use and as such would be immediately adapted if these advantages could be demonstrated. These cotton growers have already made all the possible improvements to their flood irrigated fields, such as laser levelling, shortening runs and using greater volumes of water, and must now explore other opportunities to overcome the effects of waterlogging on yield and water use efficiency.

In view of the limited experience of the application of drip irrigation on cracking clay soils a leading Wee Waa cotton grower evaluated 35 acres of drip irrigated cotton with a view to expanding to 400 - 600 acres should the results of this evaluation suggest an economic advantage. This was compared with an immediately adjacent flood irrigated field which had the same cotton variety, soil type and insect management. However, as necessarily dictated by the drip irrigation technology, the field history, fertilizer and water management program were different. The water use efficiency comparison is concerned with in-field water use and not conveyance to, or from the head-ditch or taildrain of either field as this would not change should this drip irrigation project go ahead.

The 1982/83 cotton season was very dry. The seasonal rainfall of 180mm would have been exceeded in more than 90% of all seasons, and as such waterlogging effects on yield would have been limited. The Neutron Probe was used to monitor crop water use in both fields and to schedule irrigations. The results are set out in TABLE I.

TABLE I - Drip Vs. Flood Irrigation of Cotton at Wee Waa, 1982/83

	DRIP (mm)	FLOOD (mm)
Irrigation water applied	540	460
Water stored in soil profile	150	150
Rainfall	180	180
Total crop water use	870	790
Yield ba/ac (ba/ha)	3.75 (9.27)	3.25 (8.03)
Bales/ha per megalitre	1.04	1.02

The conclusions from this evaluation were:

(i) Flood and drip irrigation technologies as they currently exist are equally efficient in dry seasons. The drip irrigation system only increased yields by increasing the total crop water use.

(ii) Using drip irrigation, a greater yield increase and an improved water use efficiency in wet seasons would be expected when waterlogging effects on yield would be greater. This has yet to be evaluated.

(iii) The costing requires an average of approximately 0.75 ba/ac yield increase at costs of $350/bale of cotton and drip system cost of $1,200/ac for this project to go ahead.

(iv) The cotton grower has evaluated, using Neutron Probe soil water monitoring and consulting inputs, the yield improvement and water saving opportunities of drip irrigation in comparison to a currently operating flood irrigation system. The agronomic and costing constraints are now known. This cotton grower is already one of the consistently highest yielding growers and is anxious to further improve. If economic circumstances change the data is available for this project to be re-evaluated and to go ahead immediately.

2. THE DETERMINATION OF WHOLE FARM IRRIGATION EFFICIENCY

In seasons of limited allocation a knowledge of whole farm irrigation efficiency is important in planning the planted area in relation to the available allocation and to calculate the exact quantity and timing of water deliveries to the farm pump site. The whole farm irrigation efficiency being the proportion of water ordered and delivered to the pump site, to the water which actually enters the crops root zone.

In the 1982/83 cotton season, cotton growers in the Gwydir Valley at Moree had a limited allocation at planting time. Prior to planting growers needed data on yield expectations for various quantities of applied irrigation water and whole farm irrigation efficiency, in order to determine the maximum possible acreage that could be planted for a given water allocation and level of risk acceptance.

Also these groups needed to minimize mid-season storage and channel evaporation by delaying water orders for as long as possible and then only ordering exactly the volume required for each day of the irrigation. This required that the exact moisture status of the crop root zone be known as well as the whole farm irrigation efficiency. Overordering, "to be on the safe side", would be avoided. The necessary data was not available and a Moree cotton grower obtained the data during the 1982/83 cotton season, for future use on the farm.

The inputs of water onto the farm were storage on hand, allocation and rainfall , TABLE II (a). By decreasing the interval between Neutron Probe readings during rainy periods it was possible to accurately determine the quantity of rainfall that infiltrated the field on which it fell and the quantity of runoff from recently irrigated fields.

The outputs of water from the farm were evaporation, soakage and crop evapotranspiration, TABLE II (b).

Evaporation was calculated as the surface area of storage, channel, taildrain or field under irrigation, multiplied by the U.S. Class A pan evaporation for that day.

Soakage was determined from Neutron Probe measurements immediately before and after each irrigation taken from aluminium access tubes placed in channel bottoms and taildrains.

Evapotranspiration was determined by measuring the field soil water content immediately before and after each irrigation using the Neutron Probe.

When balancing the inputs and outputs, TABLE II (c), a realization of necessary system design improvements which had not been previously considered was highlighted. The improvements included the need to split the main storage to reduce surface evaporation in years of limited allocation, further gate installation to re-route water in the channel system, and increased pump capacity on tailwater lift pumps.

TABLE II - Whole Farm Water Use at Moree, 1982/83

(a)

INPUTS (Ml)	
1,249	Storage on hand
2,505	Allocation
614	Rainfall infiltration
36	Rainfall runoff from irrigated fields
4,404	TOTAL

(b)

OUTPUTS (Ml)			
145	Evaporation in storage prior to September pre-irrigation		
467	Evaporation in field, tailwater and channels		
	Soakage in tailwater and channels		
475	Losses due to system design and operation which can be eliminated		
3,317	Evapotranspiration	- 1,168 Ml	Pre-irrigation
		712 Ml	First crop irrigation
		489 Ml	Second crop irrigation
		948 Ml	Third crop irrigation
4,404	TOTAL		

(c) WHOLE FARM IRRIGATION EFFICIENCY

Current Farm Efficiency $= \frac{3,317}{4,404} = 75\%$

Possible Farm Efficiency with improved irrigation design $= \frac{3,317}{4,404-475} = 84\%$

In this farm study, 75% of the water ordered and delivered to the pump site actually entered the crop root zone for crop evapotranspiration. Modification of the current system design could eliminate a loss of 475 Ml and increase the efficiency to a possible 84%. In the previous 1981/82 cotton season this farm produced 0.71 ba/ha/Ml of irrigation water and rainfall which at $350/bale of cotton means each megalitre of water has an opportunity cost of $110. Then in this 1982/83 cotton season approximately $50,000 could have been spent improving the current irrigation system. Similarly, early ordering of water "to be on the safe side" results in up to 5Ml/day evaporation loss in the farm storage or an opportunity cost of $550/day.

The benefits of quantitative irrigation water management using a Neutron Probe also became clearly apparent from this study:

(i) Reduced waterlogging/over-watering problems
(ii) Extend irrigation interval with confidence
(iii) Particularly useful to know when to start irrigation again after rain
(iv) Know exact quantity of water required for each field for each irrigation
(v) Once a set of records is established management decisions in times of limited allocation will be easier.

3. THE QUANTIFICATION OF A DEEP DRAINAGE PROBLEM

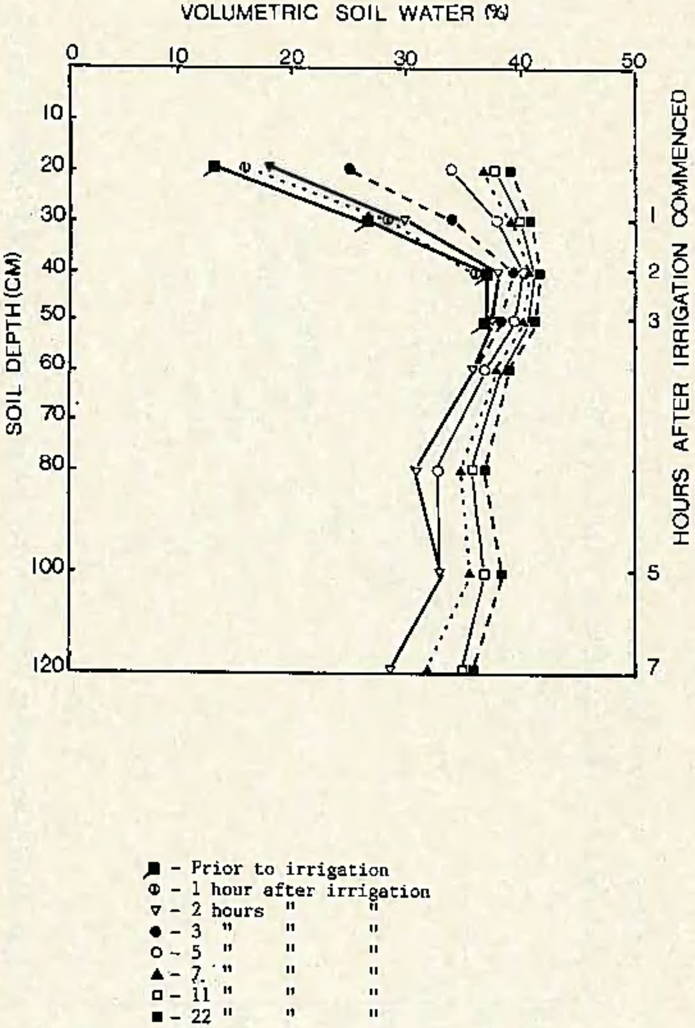
A deep drainage problem was being experienced by a farmer using furrow irrigation on an alluvial soil at Biloela, Central Queensland. This problem was quantified by the cotton consultant at Biloela using a Neutron Probe. (Figure 1)

There is a progressive increase in the depth of penetration of irrigation water with time. The irrigation water reached the 100cm depth, adding 78mm to the soil profile within 5 hours.

The rate of water advance down the furrow was very slow travelling 80 metres in 22 hours. Since there was little difference in the volumetric soil water content betwen 11 and 22 hours, a virtual steady rate of deep drainage through the soil profile has resulted within 22 hours of irrigation commencing.

Experience by fieldmen at Biloela has demonstrated that soil water extraction between irrigations doesn't exceed 100cm for high yielding cotton crops. Ideally then, management should increase the water volume to the section of this field being irrigated so as it can travel from head-ditch to taildrain within 5 hours.

Figure 1. A Deep Drainage Problem at Biloela, Central Queensland



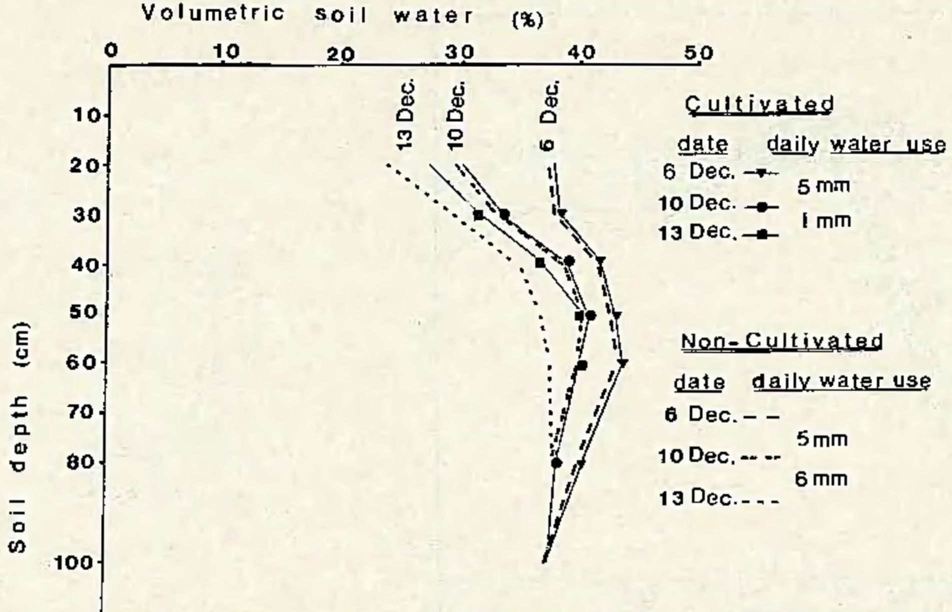


Fig 2. Root Pruning of Cotton - Emerald, Central Qld. 1983/84

4. THE ROOT PRUNIG OF COTON FROM INTER-ROW CULTIVATION

Root pruning of cotton due to inter-row cultivation, was observed to result in sudden witing and decline in daily water use of coton crops at Emerald, Central Queensland. During inter-row cultivation coton hills can be severly damaged and cotton roots exposed to direct sunlight and drying air. Improperly set cultivation equipment or poor wed control from pre-plant herbicides necessitating a 'heavy' cultivation, are the two main causes of root pruning. The effects of root pruning will be worst on compacted soils as the presence of a compacted zone gives rise to a shallower root system with a high density near the surface.

The effects of root pruning, from inter-row cultivation, on the daily water use and depth of root extraction of cotton at Emerald was quantified, using a neutron probe, by an Emerald cotton consulant. (Figure 2).

A pair of identical fields of cotton on the same farm within the Emerald Irigation Area (EIA), had the same soil water content several days after irrigation, as measured by the neutron probe on 6/12/83. In the 4 day period from 6-10/12/83 both fields had a daily water use of 5mm/day and crop roots extracted water to a depth of 80cm. Immediately after the neutron probe reading on 10/12/83 one field was heavily inter-row cultivated whilst the other was not cultivated. Subsequent neutron probe reading on 13/12/83 showed that the daily water use of the cultivated field had dropped to 1mm/day and root extraction did not exceed 50cm depth whereas the uncultivated field maintained a daily water use rate of 6mm/day and root extraction exceeded 60cm depth.

Similar observations were made on many fields throughout the ETA. It was also observed that it took approximately 6 days for the rate of daily water use by the damaged crop, to attain pre-cultivation rates. Cotton growers with wilting, root pruned crops, were advised to immediately irrigate. However in future years changing to rolling cultivators, beter incorporation of pre-plant herbicides and more consistent bed shapes will overcome this problem.

5. SCHEDULING IRRIGATIONS ON COMPACTED SOILS FOR HIGH COTTON YIELDS

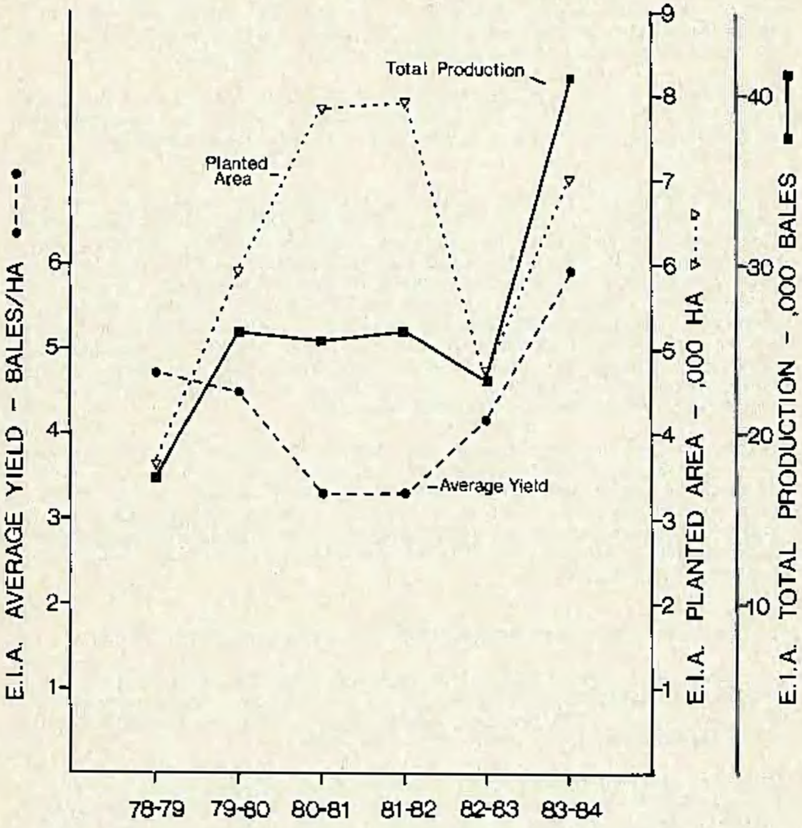
Low yields were experienced in the Emerald Irrigation Area (EIA) in the 1980/81 cotton season. Cotton growers in the area were becoming confused and disillusioned with the crop, particularly after the apparently good cotton growing conditions experienced in 1981/82.

Irrigation scheduling was finally implicated as being a major problem. How this became a problem however was not clear until a local consultant analysed some of the data he collected in 1981/82 using a Neutron Probe and was able to show the inability of cotton crops to extract water from the soil in fields with a compaction problem, (Cull,1983).

In the 1982/83 cotton season it was demonstrated that high cotton yields could be obtained in compacted fields by using soil water monitoring with a Neutron Probe and careful observation of plant appearance to schedule irrigations, (Wilcox and Cull, 1984). The demonstration field had a 178% yield improvement with 6.47 ba/ha compared to the average of 3.6 ba/ha for the past three years. This also represented a 151% yield improvement

Figure 3.

Cotton Production Statistics for the Emerald Irrigation Area (EIA)



compared to the EIA average in 1982/83 of 4.28 ba/ha. This field had yielded very close to the EIA average in each of the past three years, and as such this 151% yield improvement compared to the EIA average can be considered a substantial improvement.

In the 1983/84 cotton season more than 120 individual fields or approximantely 2/3 of all fields were monitored with Neutron Probes owned by the three cotton consultants working in the EIA. Individual field monitoring enabled irrigations to be appropriately scheduled relevant to the previous history of cropping and ground preparation and hence degree of compaction. The improvement in the total cotton production of the EIA was spectacular, (Figure 3). Production increased to 46,000 bales and averaged 6.6 ba/ha compared with 1980/81 and 1981/82 production levels of 23,000 bales and averaged yields of 3.3 ba/ha.

The importance of individual field monitoring to schedule irrigations on compacted soils for high cotton yields is illustrated for two fields both classified as the same soil mapping unit by McDonald (1981) and which would have both had the same amounts of extractable soil water prior to the commencement of cultivation. (Figure 4). However field A was severly compacted whereas field B was not compacted. Both fields had a similar soil water content immediately after irrigation. Prior to the first irrigation field B extracted 75mm of soil water from 60cm depth, before plant stress symptoms indicated a need for irrigation to avoid yield loss. The extractable soil water and depth of root extraction at the second and third irrigation was the same as for the first. The root zone in this uncompacted field had reached its maximum extent prior to the first irrigation.

However by contrast the amount of extractable soil water and depth of root extraction that was possible before the same 20b leaf water potential was reached increased between irrigations, for field A. (Fig. 4). Prior to the second irrigation field A had an extractable soil water content of 28mm which increased to 42mm 'prior' to the thrid irrigation but did not increase any further for the fourth and subsequent irrigations. Similarly the depth of root extraction increased from 40cm at the second irrigation to 60cm at the third irrigation and did not further increase during the season.

The collective experience of consultants scheduling irrigations for cotton, or cracking clay soils, using the Neutron Probe, is that there are often larger differences in extractable soil water between fields on the same soil type due to the cultivation history, than between different soil types as classified by soil scientists. In other words field experience has shown it is more important to know a particular fields cultivation history than its soil type when determining its extractable soil water content for irrigation scheduling purposes. Every field has a unique cultivation history and hence extractable soil water content which must be scheduled for, to achieve high yields. An irrigation scheduled 2-3 days late on compacted soils can cost 0.5 -1.0 ba/ha yield loss. It is for these reasons that there is no substitute for individual field monitoring when scheduling irrigations on cotton crops grown in cracking clay soils.

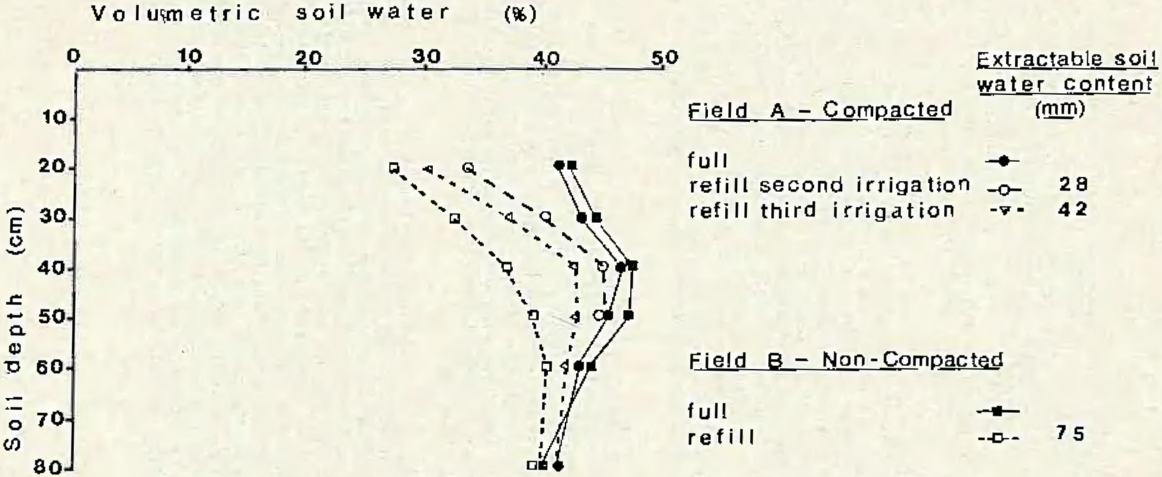


Fig. 3 The Change in Extractable Soil Water Content with Compaction – Emerald, Central Qld., 1983/84

CONCLUSIONS

In striving to increase yields and improve on farm water management, farmers are increasingly using quantitative management techniques to monitor the soil water content and to schedule irrigations. These results in an increased awareness to water related problems which are limiting crop yield of which farmers were previously unaware ór unconcerned.

These water related field production problems always demonstrate the need to further understand how best to carry out irrigation farming on clay soils in a variable rainfall environment. In many instances, no information or experience is available and a database for management decision making must be developed.

The case studies discussed illustrate the use of soil water monitoring to schedule irrigations for high yields and to develop databases to solve water related field production problems by cotton farmers in Australia.

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ACKNOWLEDGEMENTS

The author would like to acknowledge that data presented in this paper was collected by Mike Stone and Simon Struss, cotton consultants of Biloela, and Bob Gray and Bucky Rowlands, farmers from Wee Waa and Moree, Geoff Priest and John Wilcox, cotton consultants of Emerald.

Industry Matters

PRESENTATION PAPERS

HOW CAN A COTTON GROWER CHOOSE AMONG THE ALTERNATIVE MARKETING OPPORTUNITIES NOW BEING OFFERED?

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Introduction

Alternative marketing opportunities have recently become more accessible to cotton growers. This development owes much to the improved availability of electronic communication which has facilitated contact with both local and international commodity markets.

A cotton grower now has the choice of the following marketing alternatives - forward contracting, selling at harvest for immediate cash payment, the traditional seasonal pool, a call pool system, storage for later sale, hedging on the New York Cotton Exchange, dollar exchange rate hedging - or a combination of these alternatives.

How can a grower choose among this challenging array of alternatives and their combinations? A solution for just this kind of problem is portfolio analysis, an application of mathematical programming. With the ready availability now of suitable computing facilities and software for the convenient handling of the computations involved, this technique has immediate application to the selection of a marketing programme best suited to the preferences of an individual cotton grower.

Portfolio analysis, as the name implies, was originally developed for selecting portfolio combinations of investments (Markowitz 1959). Because of this historical development and the brevity of investment terms these will often be used throughout the paper to simplify discussion. Please note that the term investment will often be used instead of marketing alternative; portfolio instead of combination of marketing alternatives or marketing plan; and investor instead of grower. A direct parallel can be drawn between the terms in the application of the technique. The term portfolio is defined as one investment or a combination of more than one. In this paper portfolio will usually refer to a combination of two or more investments.

A special feature of portfolio analysis is that it provides for the selection of portfolios on the basis of two criteria - minimising risk and maximising return. Risk, or variability of return, is measured by the statistical measure of variability called standard deviation (symbolised by S).

In analysing risk, portfolio analysis allows for the so-called portfolio effect - that is if the annual returns of the individual investments in a portfolio do not increase or decrease exactly in unison (are not perfectly correlated) the standard deviation (risk) of the portfolio is less than the simple weighted average of the individual standard deviations, due to a compensatory effect. The result of this effect is that risk reduction as an objective may often be achieved by diversification of investments (or marketing alternatives). The risk reducing feature of a portfolio is demonstrated with a two-investment portfolio example in the last section of the paper.

The output from portfolio analysis is a list (or set) of the risk- and return- efficient portfolios. The significance of the expression 'efficient portfolio' will become more apparent later, but briefly it means a portfolio which has the minimum risk in its return class, or alternatively, one which has maximum return in its risk class. The investor may then select from this list the portfolio best suited to that persons particular return-risk preferences.

The basic information required for each investment is a series of T (say 10 or more) annual returns R_t ($t = 1,2,\ldots,T$ years) representing the estimated flow of annual returns characteristic of that investment. Often this is simply T years historical price data. These data are used to calculate the expected (average) return R_i^*, and variance S_i^2 (standard deviation squared) of the returns for each investment i ($i = 1,2,\ldots,N$ investments), and the covariance S_{ij} between each pair of investments i and j (see technical note (1), appendix).

The next step in the portfolio analysis technique is the formulation of a system of mathematical equations which define all attainable return-risk values associated with the possible portfolio combinations. This defines the so-called opportunity set of return-risk values. The subset of efficient portfolios is selected from the opportunity set by quadratic programming or linear programming optimisation procedures.

The paper now presents an example of the results provided by portfolio analysis for the selection of marketing alternatives by Effingham County, Illinois corn-soybean farmers. The remainder of the paper provides an outline of the principles involved in portfolio analysis.

Example of results provided by portfolio analysis

An example of the linear programming selection of efficient marketing strategies for corn/soybean farms in Effingham County, Illinois is shown in Table 1 (Klinefelter 1979). The analysis has produced a listing of efficient marketing plans (one on each line of the table). The return and risk associated with each plan appear in columns 2 and 3 respectively. Each marketing plan is the maximum return solution associated with a specified level of the grower's risk aversion indicated by the coefficient Z in column 1.

Discussion of the plans will concentrate on three levels of the risk aversion coefficient: Z = 0 representing indifference to risk (i.e., willingness to accept the highest level of variation which occurs in the returns); Z = .56 medium aversion to risk; Z = 1.12 extreme aversion to risk.

The farmer who is risk neutral (Z = 0) would contract 100 percent of the corn harvest for May delivery and 100 percent of the expected soybean production in July for harvest delivery.

The medium risk averter (Z = .56) would contract 10.9 percent of expected corn production in January for harvest delivery, 4.3 percent at harvest for January, 27 percent at harvest for March, and 57.8 percent at harvest for May. Since the last three options represent a decision to contract at harvest, the spread of delivery months primarily reflects cash flow considerations.

Table 1

OPTIMAL MARKETING STRATEGIES BY DEGREE OF RISK AVERSION FOR EFFINGHAM COUNTY:

	Expected Net Cash Flow	Estimated Standard Deviation	Corn Options							Soybean Options				
Z			Jan I-Mar	Mar I-Jan II	Mar I-Mar II	Mar-Jan II	Mar-Mar II	Mar-May II	Jan II-Cash	May I-Mar	Jul I-Mar	Mar-Cash	May II Cash	Jul II-Cash
	--------dollars--------		---------------------------percentages---------------------------							-------------percentages-------------				
.0	78061	31051						100.0			100.0			
.05	77736	27460						100.0			82.7		17.3	
.11	76995	20945					27.0	72.6	.4		51.4		48.6	
.16	76601	19456				11.6	27.0	61.4			38.7		51.8	9.5
.22	76601	19456				11.6	27.0	61.4			38.7		51.8	9.5
.28	76601	19456				11.6	27.0	61.4			38.7		51.8	9.5
.33	76072	18555				19.9	27.0	53.1			24.4	5.2	54.9	15.5
.39	75635	17865	2.0			19.9	27.0	51.2			19.8	8.0	55.0	17.2
.44	75635	17865	2.0			19.9	27.0	51.2			19.8	8.0	55.0	17.2
.50	70470	11951	10.9			4.3	27.0	57.8		31.9		10.2	57.9	
.56	70470	11951	10.9			4.3	27.0	57.8		31.9		10.2	57.9	
.61	70470	11951	10.9			4.3	27.0	57.8		31.9		10.2	57.9	
.67	70470	11951	10.9			4.3	27.0	57.8		31.9		10.2	57.9	
.72	67167	9357	35.4					64.6		29.2		25.3	45.5	
.78	62049	5535	71.0					29.0		25.4		47.2	27.4	
.84	62049	5535	71.0					29.0		25.4		47.2	27.4	
.89	60723	4697	44.8		31.8			23.4		27.4		48.5	24.1	
.95	58018	3032		53.5	31.8			14.7		32.1		49.6	18.3	
1.00	58018	3032		53.5	31.8			14.7		32.1		49.6	18.3	
1.06	58018	3032		53.5	31.8			14.7		32.1		49.6	18.3	
1.12	57763	[illegible]		84.7				15.3		32.9		49.0	18.1	

Source : (Klinefelter 1979) .

This individual would also contract 31.9 percent of the expected soybean production in May for harvest, sell 10.2 percent at harvest for cash, and sell 57.9 percent for cash out of storage in May.

The extreme risk averter (Z = 1.12) contracts 84.7 percent of the expected corn production in March for January and contracts 15.3 percent at harvest for May. The associated soybean marketing strategy would be to contract 32.9 percent of expected production in May for harvest, sell 49 percent for cash, and sell the remaining 18.1 percent for cash in May.

Note that both the maximum expected net cash flow and the estimated standard deviation decline as the level of risk aversion increases. This is a normal portfolio analysis phenomenon. Net cash flows decline from $78,061 in the optimum solution for the risk neutral decision maker to $57,763 for the most risk averse. Corresponding to these expected net cash flows, the estimated standard deviation decreases from $31,051 to $2,898 respectively. Based on these strategies the risk indifferent decision maker would expect his annual net cash flow to be above $47,009 ($78,061 - $31,051) with 84 percent certainty while the most risk averse would expect annual net cash flows of greater than $54,864 ($57,763 - $2,898) with the same degree of certainty. Although the income variability would be less for the risk averse individual, the farmer would also be foregoing large variations of returns above the expected levels.

The financial results in the previous paragraph indicate the usefulness of portfolio analysis in providing information on the likely variability of the returns associated with the optimal marketing plans.

Portfolio analysis

The remainder of the paper will discuss the basic principles underlying portfolio analysis. It will be demonstrated how the technique provides for the computation of a convex opportunity set and how this is particularly relevant as a model for choice.

Basic assumptions of portfolio analysis

Portfolio analysis is based on four assumptions (Francis and Archer 1979, p5): firstly, investors visualize returns to an investment as having a defined pattern of variability, that is, a probability distribution; secondly, investor's risk estimates are proportional to the variability of the expected returns; thirdly, investors are willing to base their decisions solely in terms of expected return and risk; and fourthly, for any given level of risk, investors prefer higher returns to lower returns. Conversely, for any given level of rate of return, investors prefer less risk over more risk.

These preferences are shown graphically in the indifference curve map of Figure 1.

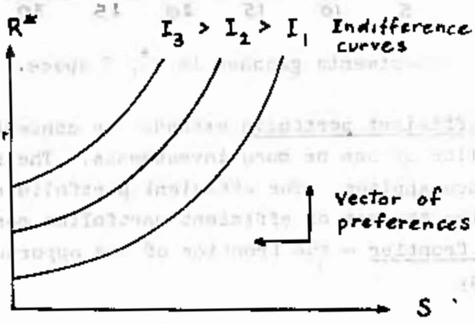

Figure 1: Indifference curve map for R^*, S preferences.

The concepts of 'dominant investment' and 'efficient portfolio'.

The two related concepts of a 'dominant investment' and an 'efficient portfolio' are basic to portfolio analysis. They follow from the above assumptions.

A dominant investment has one of the following attributes: the lowest risk S in its R^* class; or the highest R^* in its risk class; or both an R^* that is above another investments R^* and an S that is below the other investments S.

To illustrate the principle of dominance, consider the investments ABCDEF in Figure 2. These investments have the expected rate of return R^* and risk S indicated in the diagram. Note that D is dominated by both A and B; E by B and C; and F by C. A, B and C are not dominated.

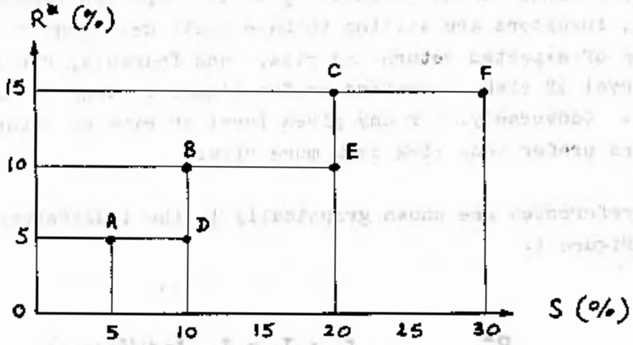

Figure 2: Investments graphed in R^*, S space.

<u>The term efficient portfolio</u> extends the concept of dominance to portfolios of one or more investments. The same principle of dominance applies. The efficient portfolio concept is used to determine the set of efficient portfolios comprising the <u>efficient frontier</u> - the frontier of the opportunity set of portfolios.

Figure 3 depicts the general shape of the investor's opportunity set. It comprises all available investment combinations graphed in R^*, S space.

The opportunity set has an efficient frontier which is bent towards, or convex, to the R^* axis (for the reason explained below) and overall takes on a scalloped quarter-moon shape. The convexity of the opportunity frontier is of primary importance in the use of portfolio analysis as a choice model. The set of portfolios which comprise the efficient frontier is represented by the curve AD in Figure 3. The dominance principle can be demonstrated with the portfolios B C and E. Both B and C (and any portfolio in the sector BCE) dominate E. Likewise any portfolios on the frontier below A or to the right of D are dominated by A and D respectively.

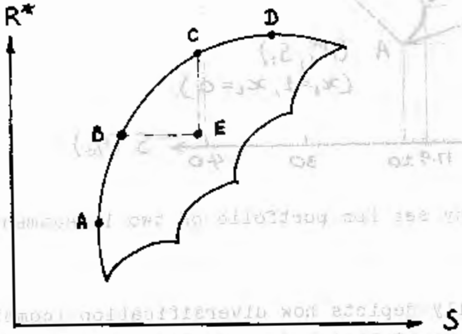

Figure 3: The opportunity set of portfolios

Relationship between convexity of the opportunity set and the risk reduction of a portfolio.

A simple two-investment portfolio is now used to demonstrate the significance of the convexity of the opportunity set frontier, and its association with the reduction of risk and the degree of correlation between the returns of the investments (see technical note (2), appendix for an explanation of correlation).

Recall that earlier in the paper it was mentioned that if the annual returns of investments are not perfectly correlated this has the effect of reducing the standard deviation (risk) of a portfolio comprised of the investments. The effect of the degree of correlation on a two-investment portfolio is illustrated in Figure 4 which shows, for a particular numerical example, the return-risk values associated with different proportions of investments 1 and 2, given the three degrees of correlation of r_{12} of −1, 0, +1. Data for the two investments are investment 1: $R_1^* = 5\%$, $S_1 = 20\%$; investment 2: $R_2^* = 15\%$, $S_2 = 40\%$.

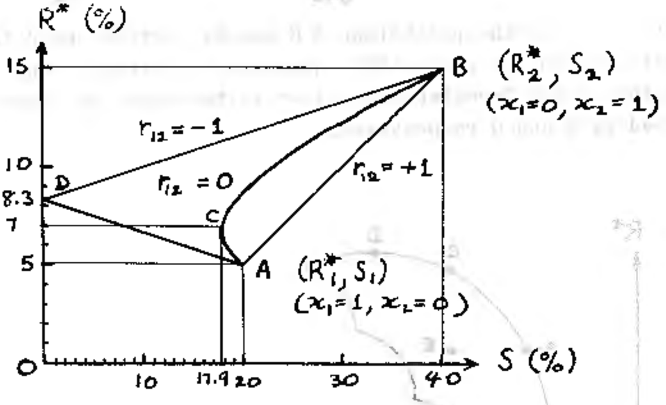

Figure 4: Opportunity set for portfolio of two investments, r_{12} of -1, 0, +1

The figure graphically depicts how diversification (combination of investments in a portfolio) and correlation affect risk in the portfolio. A and B represent the (R^*, S) values when the portfolio comprises only one investment. Let x_1, x_2 represent the proportion of the portfolio comprising investments 1 and 2 respectively, with x_1 plus x_2 always equal to 1. For example when $x_1 = 1$, $x_2 = 0$ and the portfolio comprises only investment 1. At A: $x_1 = 1$, $x_2 = 0$, (R^*_1, S_1) is (5, 20).

At B: $x_1 = 0$, $x_2 = 1$, (R^*_2, S_2) is (15, 40).

The three loci of (R^*, S) values AB, ACB, and ADB each represent the opportunity set of (R^*, S) values for the possible combinations of investments 1 and 2 (when x_1 and x_2 each range between 0 and 1, and $x_1 + x_2 = 1$) and when the correlation coefficient between investments 1 and 2 r_{12} is +1, 0, and -1 respectively.

Note that when $r_{12} = +1$ AB is a straight line because the (R^*, S) values of the various combinations of investments 1 and 2 are a simple (linear) weighted average of (R^*_1, S_1) and (R^*_2, S_2). The expected return R^* values of the portfolio combination are <u>always</u> a simple (linear) weighted average of

R_1^* and R_2^*. However the standard deviation S values of the portfolio combinations behave differently (see technical note (3) appendix). The S values for $r_{12} < +1$ for portfolio combinations are not linear averages of S_1 and S_2. As r_{12} becomes progressively less than 1 the portfolio S value becomes progressively reduced. This results in loci such as ACB becoming more bent towards (or convex towards) the R axis. The greatest reduction of S occurs for the loci ADB when $r_{12} = -1$, in fact at one unique combination of investments 1 and 2 represented by D, S is zero.

The above principle of risk reduction still applies when the portfolio comprises more than two investments, and the opportunity set continues to be convex.

In practice, the extreme values of correlation $r_{12} = +1$ and $r_{12} = -1$ are never achieved so that the risk reduction is somewhere in between zero effect and its maximum effect, i.e. between the loci like ADB and AB in figure 4. For some price series, such as those for marketing alternatives of the same crop, we might expect to find a fairly high degree of correlation and a minimal risk reduction advantage from diversification. However, this needs to be checked out, because as shown in the corn/soybean marketing example, risk reductions can occur from diversification within each crop.

The portfolio effect (and associated convexity) is necessary for a mathematical solution as indicated in the diagramatic model of figure 5. The portfolio which satisfies the investor's preferences is that associated with the R^*, S values at the point of tangency at C between the investor's indifference curve I_1 and the efficient frontier AB.

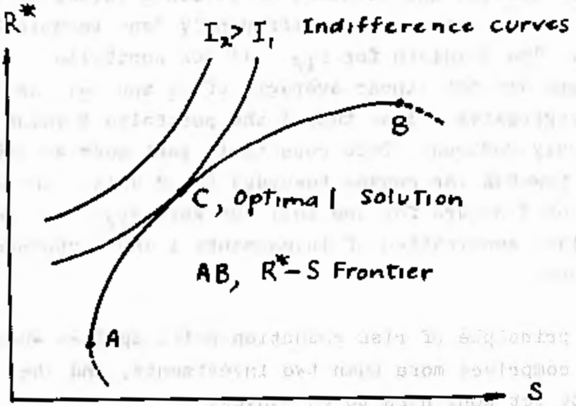

Figure 5: The complete portfolio analysis choice model.

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APPENDIX

TECHNICAL NOTES

(1) Expected return $R^* = \sum_t R_t/T$, $t = 1, 2, \ldots, T$ years.
(where $\sum_t R_t = R_1 + R_2 + R_3 + \ldots + R_T$).

Variance $S^2 = \sum_t (R_t - R^*)^2/T$

Standard deviation $S = (S^2)^{1/2}$

Covariance between two investments 1 and 2,
$S_{12} = \sum_t (R_{1t} - R_1^*)\ (R_{2t} - R_2^*)/T$

(2) Correlation between two investments 1 and 2 is measured by the correlation coefficient $r_{12} = S_{12}/S_1S_2$.

Two investments are said to be positively correlated ($r_{12} > 0$) if they tend to increase or decrease together and $r_{12} = +1$ (perfect positive correlation) represents the maximum value for r_{12} when the changes vary exactly in unison. The investments are said to be negatively correlated ($r_{12} < 0$) if one tends to increase when the other decreases, and vice versa, $r_{12} = -1$ (perfect negative correlation) being the minimum value for r_{12} for the case of exactly compensating changes. The investments are uncorrelated ($r_{12} = 0$) when they tend to change with no connection to each other. The range of r_{12} is therefore $-1 \leqslant r_{12} \leqslant +1$.

(3) The following equations are for a portfolio comprising two investments denoted by subscripts 1 and 2.

Expected return for portfolio,
$R_p = x_1R_1^* + x_2R_2^*$, an average of R_1^* and R_2^* weighted by x_1 and x_2.

Standard deviation for portfolio,

$$S_p = [x_1^2S_1^2 + x_2^2S_2^2 + 2x_1x_2r_{12}S_1S_2]^{1/2} \qquad (1).$$

When $r_{12} = +1$ S_p has its maximum value because the last term of equation (1) $2x_1x_2r_{12}S_1S_2$ is at its maximum value. Also when $r_{12} = +1$, $S_p = x_1S_1 + x_2S_2$, a linear weighted average as R_p^* always is. This case is represented in Figure 4 by the straight line AB, the loci of (R_p^*, S_p) as the respective proportions of investments 1 and 2, x_1 and x_2, change.

When $r_{12} = -1$ S_p has its minimum value because the last term of equation is at its minimum negative value. This case is represented by the loci ADB in figure 4.