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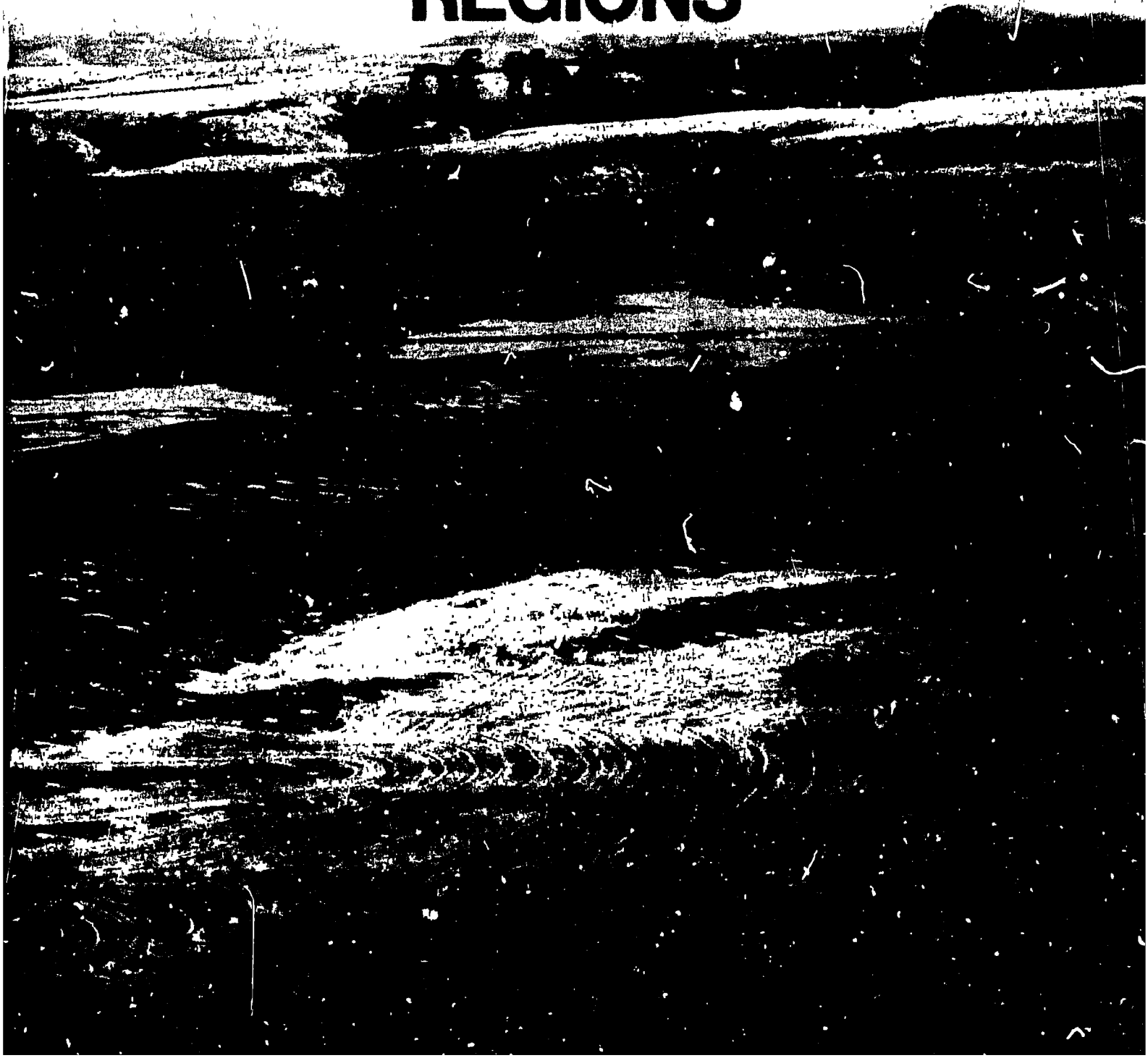

DRYLAND AGRICULTURE in WINTER PRECIPITATION REGIONS of the WORLD

STATUS OF THE TECHNICAL ART

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COVER

An aerial view of interspersed dryland cereal cropping and rangeland in the central region of the U.S. State of Oregon. Fallow land, cropped fields with stubble rows, and chaff piles are visible. The circular mounds in the interspersed, uncultivated rangelands are geologic formations.

Photo taken by Thomas Nordblom, agricultural economist, Oregon State University.

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The views and interpretations in this publication are those of the Oregon State University Dryland Agriculture Technical Committee and should not be attributed to the Agency for International Development or to any individual acting in their behalf.

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PREFACE

The Program

Oregon State University and the state's agricultural experiment station have devoted major effort over many years to developing technology and practices to improve dryland agricultural production. A primary thrust has been conservation and beneficial utilization of available moisture. Numerous disciplines have participated in the ongoing effort. As a result, a significant body of information and experience has accumulated concerning dryland agricultural production dependent on winter precipitation.

OSU staff members participated in international programs in Turkey and Jordan aimed at increasing cereal production and expanding cereal production research and extension. These programs, plus the interest and experience of OSU in dryland agricultural development, led to discussions with the U.S. Agency for International Development (AID) and, ultimately, resulted in AID awarding a five-year 211(d) grant to OSU to marshall and expand its expertise and to develop a center of excellence in dryland agriculture that could be harnessed for application to developing countries. The grant, entitled Moisture Conservation and Utilization in Low Winter Rainfall Areas of LDCs, was launched in mid-1975.

A Technical Committee (Techcom) was selected from OSU staff members of the crop science, range, soils, agricultural engineering, and agricultural and resource economics departments, plus a representative from the OSU library. The Techcom became the nucleus and operating arm of the grant. Meetings were held weekly to assess progress and determine direction. The Techcom also undertook study trips to the Middle East, North Africa, and Australia.

The SOTA

One of the Techcom's fundamental responsibilities involved distilling available information and knowledge into a single document that would attempt to portray the status of the technical arts (SOTA), knowledge from the scientific community focused on conservation and utilization of moisture in the production of crops and livestock. The SOTA refers to conditions in semi-arid regions

receiving moisture, sometimes as snow, during winter months of the year.

Dryland agriculture, as it's practiced around the world, ranges from basic and casual to sophisticated and tightly managed. But, overall, weather and moisture availability intrude as the overriding constraints. Identifying the levels of technology and relating them to the social, economic, institutional, and political forces at work ranks as a task no single document can accomplish in totality.

The material that follows, however, touches on numerous aspects of the drylands--the problems, the limiting factors, the opportunities and potentials. Perhaps the single most significant complexity, and one the Techcom believes has encouraging potential, lies in the inter-relationship of interfaced livestock and dryland agriculture.

The SOTA addresses this important facet after presenting chapters devoted to the various elements--physical, social, economic--that bear upon dryland agriculture. Each chapter strives to construct an overview based on contemporary knowledge. A list of references plus a list of additional information sources accompanies each chapter, thereby providing rich opportunity for additional reading.

An overall summary precedes the subject matter chapters.

SUMMARY

Drylands are more than exclusively cereal producing regions. Farmers grow both cereals and forage for livestock with the mix dependent upon relative prices and values of cereals and livestock, as well as cost and availability of production inputs. Relatively abundant and cheap labor may tilt the balance in favor of livestock production.

Viewed in another way, technologies and crop rotations which assign importance to forage and livestock production may stand a better chance of succeeding because they will employ more of the available resources than alternatives which concentrate on cereal production to the exclusion of livestock. Furthermore, combined operations can be expected to benefit smaller farms where labor tends to be most abundant.

Little evidence exists for the profitability of new, mono-crop cereal production packages, and the information that is available presents mixed results, especially when weather-related variability is taken into account. Furthermore, none of the studies reviewed in researching the SOTA takes account of all impacts of cereal production practices on feed for livestock. In other words, returns were

not reduced to reflect any loss in forage availability. Such calculations could only serve to reduce the expected viability of the packages.

It is suggested that future work in developing dryland farming efforts concentrate on strategies which provide an explicit role for inter-related forage and livestock production and on strategies designed to mitigate weather-related risk. The two needs may be highly compatible.

I. INTRODUCTION

The world's arable crop land comprises an estimated 1.4 billion hectares. Only about 10 percent is irrigated; the remainder depends on annual rainfall. Nearly 0.6 billion rainfed hectares are considered semi-arid to arid, i.e., receive less than 500 mm of annual precipitation. However, these low rainfall zones produce a major portion of the world's cereal crops. Approximately 450 million people inhabit low rainfall areas of developing countries, a population expected to increase to 550 million by 1980.

These same lands also constitute an important resource for improving agricultural production internationally through improved conservation and utilization of available moisture.

Emphasis on increasing dryland production (and concurrently reducing degradation--overgrazing and erosion) has become evident recently in many developing regions. Few successes of major yield increases are available. Turkey stands as an exception. With the bulk of its cereal production occuring under dryland conditions, the Turkish government has been pursuing dryland improvement programs for over a decade. Turkey has ceased to be a net importer of grain and presently has large potentially exportable surpluses.

Programs to improve dryland production, to be successful, require trained, competent nationals. Relatively few individuals from developing regions have been exposed to training in dryland crop or livestock production techniques. Without a strong cadre of local personnel to conduct research and extension activities, there is little chance of a sustained increase in dryland crop production.

Production technologies, as well as training, need to be adapted to local conditions. For dryland crop production, the "package of practices" has enjoyed some success, particularly in Turkey. A package combines tillage for moisture conservation and seedbed preparation, attention to planting adapted varieties at optimum rates and dates, carefully timing and applying fertilizers in relation to moisture supplies, practicing timely weed control in both fallow and crop seasons, and harvesting in an appropriate manner. Timing and sequence are critical; failure to perform elements on time and in order can nullify the advantage of the other elements. Introducing an improved variety without concurrent weed control, or fertilizer, or improved seedbed can produce yields only equal to--or worse than--local varieties. Applying fertilizer and leaving weeds uncontrolled

may cause an upsurge in weed growth and a severely diminished crop yield.

Economically and agronomically effective production packages require extensive applied field research conducted over relatively long time periods. Site specificity in tuning the package to local conditions is necessary. The basic climate and soils data needed to design a program often are not available in developing regions. Or, if the information can be obtained, personnel with capability to interpret and apply it cannot be found.

The development of a complete production package for the drylands in developing countries does not appear feasible for the immediate future. Numerous resources (seed, fertilizer, herbicides, equipment, etc.) are either unavailable, beyond economic range, or too risky for most (small) operators. But certain elements do have immediate applicability in many instances. The key to increases in dryland crop yields involves sorting out those practices which generate the greatest benefits and which best fit local traditional systems. As new resources become available and as additional field research is conducted, the other elements of the production package can be investigated for applicability.

Farms in the world's dryland zones generally produce both cereals and livestock. Extensive research and development has focused on increasing the cereal production on these farms. Far less is known about the roles of livestock and forage in the total farm organization as well as the potential presented by expanded areas of complimentarity between cereal and livestock.

Rangeland-animal systems in developing dryland areas, in order to improve, also face many interwoven, complex problems:

- Heterogeneous climates and soils;
- Deteriorated rangelands condition with deterioration increasing at an accelerated rate;
- Emphasis on sheep production (primarily fat-tailed breeds) with minimal attention to cattle and goat production;
- Transportation problems for marketing animals produced;
- Few facilities or equipment for haying or storing forage;
- Essentially no facilities for stored or frozen meats;
- Emphasis on number of animals, with little regard for quality, of the animals owned;
- Poorly defined property rights both for land and animals.

The underlying physical and economic relationship between cereal and livestock enterprises needs to be investigated and clarified for several reasons. Improved livestock production has significant potential for utilizing seasonally underemployed labor in cereal production zones. Therein lies an opportunity for increasing incomes of small farms which tend to have relatively more available labor than land. Incidental forage production (as crop residue and weeds) on these farms also constitutes an important feed source for range livestock during periods of reduced range forage availability. The economic trade-offs between forage-livestock production and cereal production are important since certain techniques often advocated for increasing cereal production-such as clean fallowing--reduce supplies of forage for grazing.

II. SEMI-ARID CLIMATES AND DRYLAND AGRICULTURE

A. Defining Semi-aridity

A 1974 symposium, "Frontiers of the Semi-Arid World: An International Symposium," had, among its announced goals, defining semi-aridity (Conselman, 1977). The goal was not realized as each invited specialist established his own criteria to discuss semi-aridity.

F.B. Conselman, symposium proceedings editor, in an attempt to summarize, ventured his own definition: "As a starter, semi-aridity might be deemed to include the band between 50 and 100 inches (1250 and 2500 mm) net annual evaporation rate, these figures to be adjusted empirically on the basis of existing 'understanding'." Net evaporation includes the effects of precipitation, wind, radiation, temperature, humidity, and seasons.

The definition, however, lacks simplicity. The following though less rigorous definition will be used in this text. Arid areas, will be defined as commonly having 100-250 mm annual precipitation, though rainfall may be higher when it occurs predominantly during the summer months. Semi-arid areas normally receive between 250-500 mm of moisture with the larger amount characteristic of a summer or hot months rainfall regime.

Uncertainty of agricultural production generally increases as moisture declines, and may be the greatest impediment to farming in semi-arid environments. A 1931 to 1976 study of the effects of rainfall variability and crop yield in central Washington, a dryland region of the U.S., revealed that the standard deviation of yield was 692 kg/ha with an average of 1593 kg/ha. The study considered only a wheat-fallow rotation which tends to reduce variability. The variability of annual cropping would have been much higher.

As a mechanism for reducing economic risk, farmers in semi-arid environments often produce both cereals and livestock, particularly where adjacent or nearby nontillable land is available for pasture. Areas of complementarity exist, especially in the utilization of labor but competition also exists for land and capital inputs.

B. Semi-arid Regions*

Regions considered semi-arid usually lie between regions of arid and humid climates. Those on a continent's west coast generally have dry summers and cool, moist winters. Areas to the east experience higher temperatures with rainfall that increasingly occurs during the growing season or the summer months.

Winter rainfall zones, the primary focus of the status of the technical arts, can be classified into 1) Mediterranean-type climates and 2)interior dry climates. Mediterranean climates generally occur between latitudes of 30° to 40° and on a continent's west face. In summer, when winds and high pressure belts move northward, dry regions extend to higher latitudes, or up to 40°; dry summers characterize the Mediterranean climate. As the sun moves south in the winter, the region receives occasional precipitation.

The Mediterranean types of climates, in addition to bordering the Mediterranean Sea, are found in southern, central coastal, and interior sectors of California, in central Chile, along southwest Africa's coastal plain, and in some areas of Australia. The climate generally produces mild winters and hot--though not excessively hot--summers. Rainfall is usually moderate, but occasionally occurs in short, high volume bursts. Frosts are rare.

Interior lands east of the Mediterranean zone, but west of the summer rainfall regions, experience cold winters and have essentially winter precipitation. Rainfall efficiency tends to be low; these areas have intense sunshine with strong winds. Summer temperatures may be very high with high surface wind velocities. Distance from an ocean (and its associated influences) and presence of mountain barriers are factors that establish the existence of semi-arid areas. The world's major semi-arid zones with cold, rainy winters occur in northern Africa, the middle latitude dry climates of Eurasia including Iraq, Syria, most of Asiatic Turkey, and the Iranian Plateau, as well as northwestern North America (Figures 2, 3, and 4).

The North American semi-arid winter precipitation zone extends westward from the Rocky Mountains. The semi-arid Pacific valleys of North America receive rainfall during the winter months, but vary from more humid areas in the north to extremely arid areas in the south. Baja California, midway between northern and southern extremes of the region, has the lowest rainfall.

The inter-mountain area east of the Sierra Nevada-Cascade mountain ranges exhibits warm summer temperatures and cold winters. The region roughly divides into two areas: the northern cool desert, often called the sagebrush zones: and the southern warm desert, or creosote-brush zone. Precipitation patterns in the southern part are biannual having two distinct peaks, one occurring during winter and one during the warm season. Winter rainfall is more pronounced in the north.

The sagebrush, or northern zone, has two major subdivisions:

*Material in the following two sections largely has been summarized from Crop Production in Dry Regions by I. Arnon.

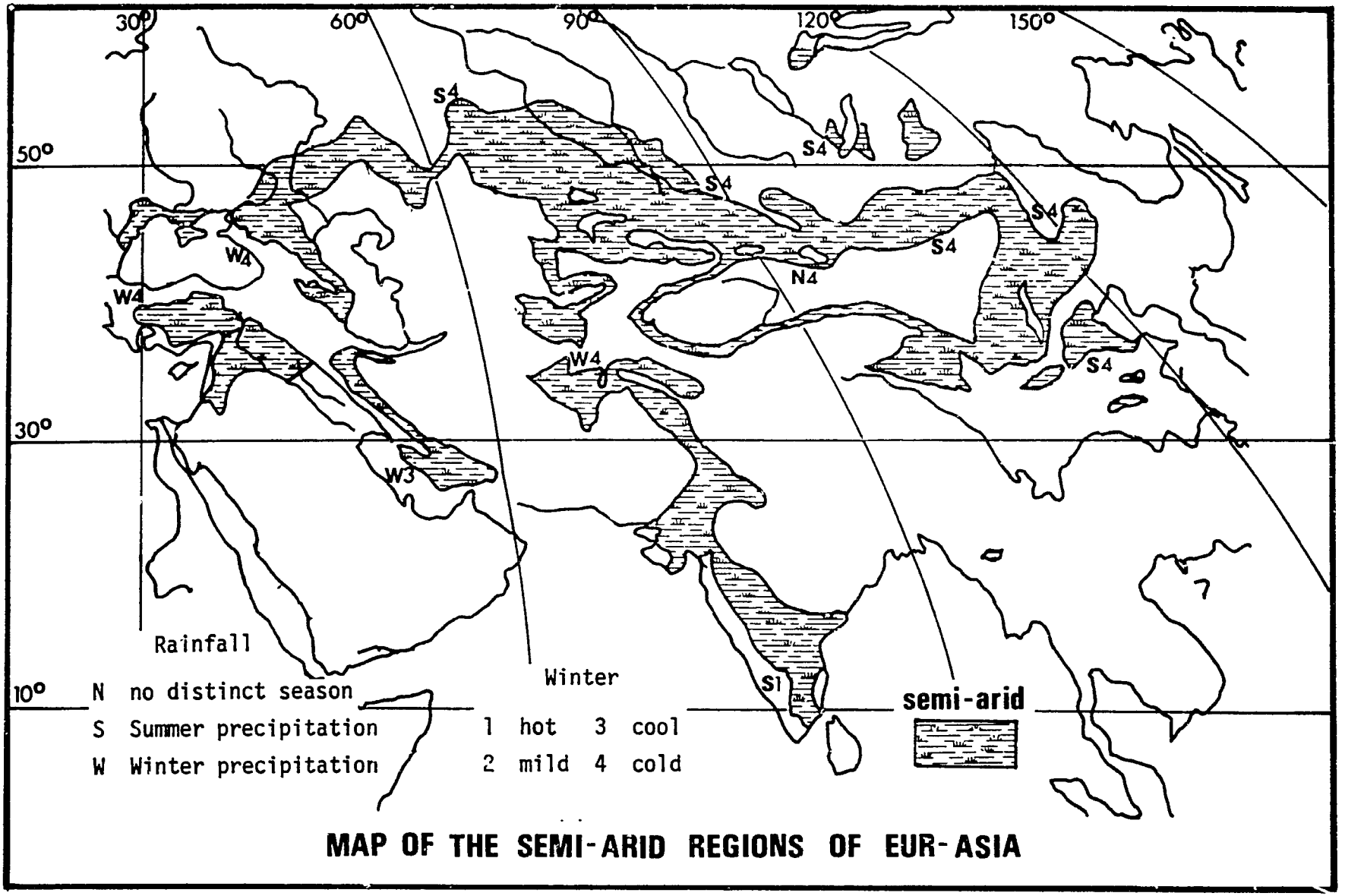
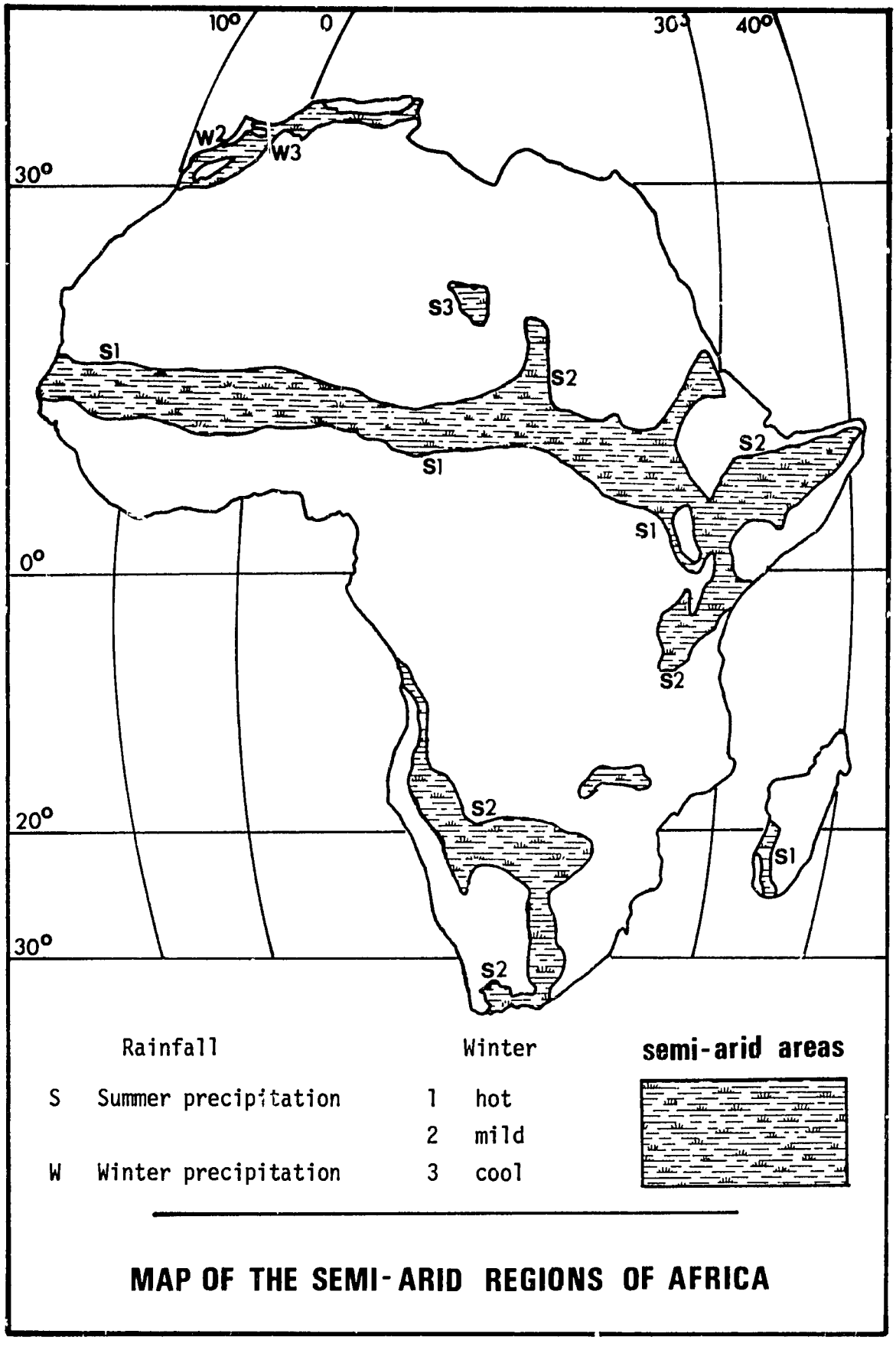


Figure 2 (after Arnon)



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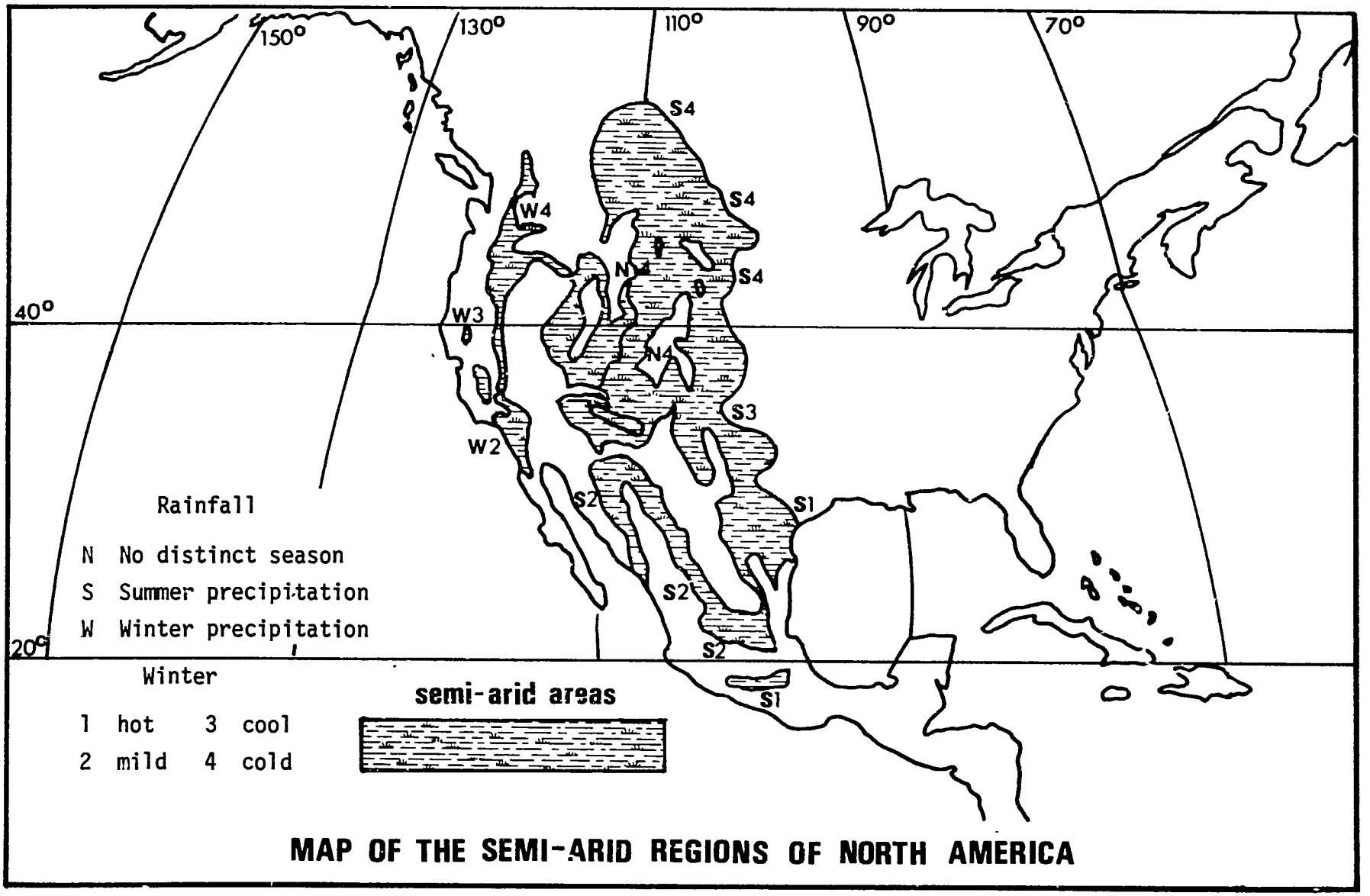

Figure 4 (after Arnon)

the Colombia Basin in the north and the Great Basin in the center. The former, a medium altitude dry plateau, stands as one of North America's major winter wheat regions. The Great Basin is typical high altitude range country with extensive grazing and extremely sparse settlement, except where ample water is available for irrigation.

South America's arid zone (Figure 5) forms a long narrow strip along the western coast between the sea and the Andes mountain range. The region east of the Andes is semi-arid; it extends inland and includes the Argentinian Great Pampas. Most precipitation in South America falls during the summer months and often occurs in a torrential manner which can create the appearance of a tropical climate in a very short time span.

Australia (Figure 6) is almost exclusively an arid and semi-arid continent excepting portions in the northeast and small portions in the south. Central Australia has hot desert climates with mild to hot winters. However, sub-tropical belts and semi-arid areas surround the desert. In most dry areas rainfall volume normally decreases in relation to distance inland. Rain occurs in the north mainly during the summer; for the south, winter precipitation predominates.

C. Arid Agriculture

In the semi-arid areas of the Near East and North Africa, traditional agriculture is based dominantly on the production of winter cereals, with wheat grown in the higher rainfall zones and on deeper soils possessing greater moisture storage capacity. Barley is grown in areas with less rainfall and on shallower soils limited by storage of subsoil moisture from the summer fallow period. Winter cereals are sown generally on poorly maintained, or "weedy," fallow. As rainfall decreases, the fallow period is increased with some areas producing a crop once out of three years. In some areas, the land might lay fallow for an undetermined number of years until favorable rainfall conditions occur that provide enough stored soil moisture to produce a cereal crop. Weeds are a major problem with this system of cropping and the weed cover restores itself quickly after harvest.

In the past, those soils with better crop production potential, from a combination of higher rainfall and greater soil moisture storage, have been cultivated. In recent years, many marginal areas have been used for cereal production. Cultivation has been extended up the slope to steeper areas with shallower soils producing accelerated soil erosion with more frequent crop failures.

Forage legumes, primarily vetch, subterranean clover, medicago species, and edible legumes, such as chick peas and faba beans, are produced under dryland conditions throughout developing areas. These nitrogen-fixing legumes make a contribution towards improving soil fertility, as well as supplying forage for livestock and a better protein component in human diets.

Two critical factors for determing the boundaries between

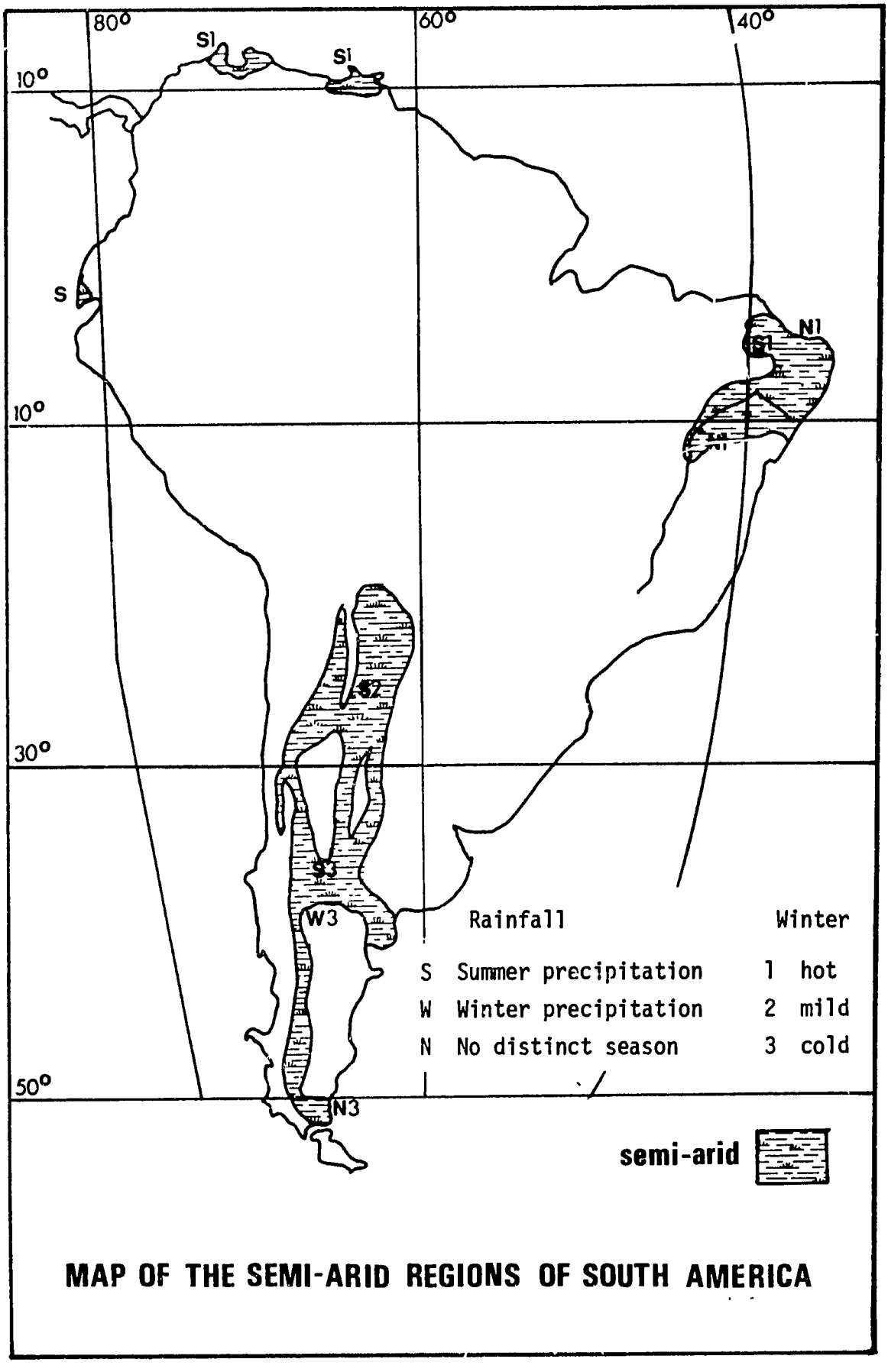

Figure 5 (after Arnon)

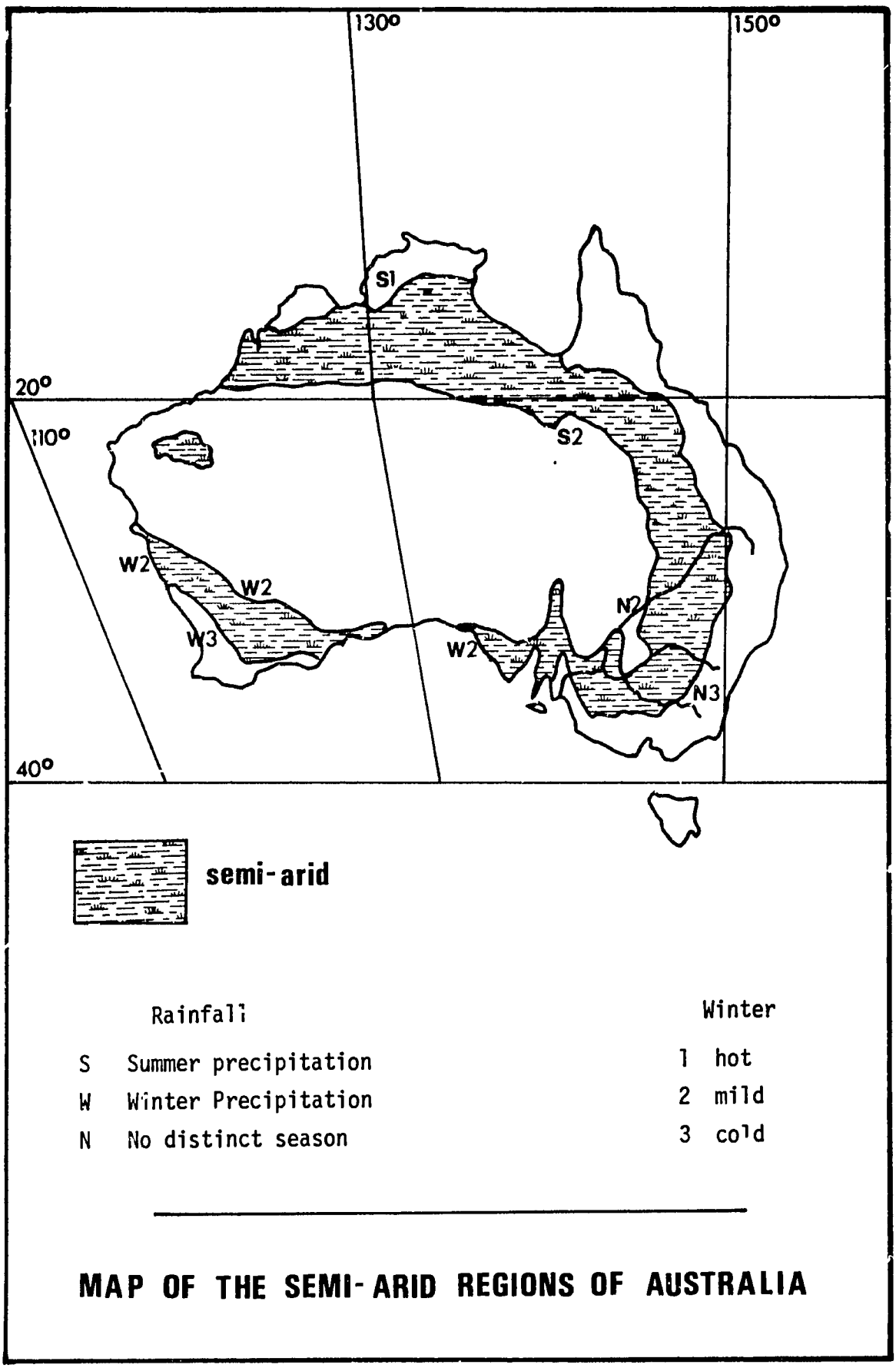

Figure 6 (after Arnon)

dryland production and arid grazing, are the amount and reliability of annual rainfall. A mean annual rainfall of 240 mm, with a variability of 33 percent, was found to be virtually the minimal requirement for regular dryland farming. However, where variability was greater, so was the amount of rainfall required.

Dryland cropping in Australia can be found in semi-arid regions with 250 to 500 mm rainfall. Extensive land areas originally had to be cleared of trees and shrubs. Average crop yields on cleared land declined over time as the soil nutrients--initially low--were reduced further. In the South Australian winter rainfall area, yields averaged only 255 kg/ha; crop failures were quite frequent. As yields decreased, continuous cropping to wheat was replaced by summer fallow systems which allowed for some storage of soil moisture, and provided a period when soil humus could decompose to improve the supply of nitrogen, phosphorus, and sulfur for the production of the following crop. The summer fallow system of farming resulted in accelerated erosion and a decrease in already low levels of nitrogen, phosphorus, and sulfur present in the soil; the number of crop failures increased.

The problem of deteriorating soil productivity was eventually solved through a system of ley* wheat rotation farming. This system included the introduction of nitrogen-fixing legumes fertilized with phosphorus and sulfur to gain maximum production of the legume and to contribute nitrogen to the cereal crop that followed. Two major rotation systems were developed. One employ medics while the other relies on subterranean clover. The annual medics have been dominantly used in the areas where the soil pH was neutral or higher, which frequently coincides with areas of some summer rainfall. The hard seeds of the annual medics can be managed for regeneration of the legume in a two-year, wheat-legume rotation. In other areas where the soils were moderately acid, subterranean clover was the dominant legume species introduced. A three to four year production of subterranean clover was followed by two to three years of a cereal crop before the subterranean clover was reseeded.

In both systems, the legumes provide pasture and hay for sheep and improve the nitrogen supply for the cereal crops. Approximately one-third of the current total sheep production of Australia is maintained on wheat farms that make use of wheat-legume rotation cropping systems.

D. Soil Moisture Conservation

1. Various approaches

Availability of moisture controls crop production in semi-arid regions. Logic argues that moisture needs to be conserved to increase its usefulness and availability to crop plants.

Over the years, agricultural researchers have developed numerous theories and practices for moisture conservation--and discarded most of them. During the early 1900's, a U.S. researcher, Hardy W.

*ley: arable land used temporarily for hay or pasture.

Campbell, proposed that the top layer of soil be worked to form a dust mulch (in the fallow system) to break capillary connections and prevent loss of moisture from the soil surface (Hargreaves, 1948). The basis was a belief that water rose from moist subsoil to the soil surface by capillary movement. Investigators found that capillary movement of water upwards, except as carried by plant roots, was practically nonexistent in dryland areas where no shallow water table existed. The fallacy of dust mulching was proved before 1915 (Chilcote, 1912). The Dust Bowl drought that occurred during the 1930's in the Great Plains of the United States was testament to the devastation of blowing soil. The finely pulverized surface of a dust mulch was not only prone to wind erosion, it increased water run-off (Lockeretz, 1978).

Another concept held that extremely deep plowing or subsoiling would permit more water to enter, and be retained by, the soil as well as increase the zone where crop roots could develop freely. Deep plowing and subsoiling practices were discarded because of high costs and failure to conserve additional moisture. The loose, open soil increased water loss by evaporation. Cultivation depth was found to have little effect on root development. Crop roots extended well below the disturbed area, but occupied only the moist soil area. Crop growth was sufficient to exhaust the available water in most seasons.

2. Summer fallow

A common practice has evolved that tends to balance cost and effectiveness of retaining moisture. Stubble from a previous crop remains on the land through winter, retaining snow and checking run-off and erosion. Spring plowing follows to control weeds that usurp valuable water. This operation ordinarily occurs in early spring to avoid prolonged weed growth or moisture loss from plowing in hot weather. Thereafter, cultivation keeps the land weed-free during the summer. The land rests during the normal growing season; it is in fallow. Fallowing in the U.S. Pacific Northwest has the primary function of conserving soil moisture during the summer and providing a period of time for nitrogen to be released from soil organic matter.

Fallow is only effective in conserving soil moisture when the weed and volunteer growth is carefully controlled. Ordinarily, all moisture in the upper 20 cm of soil will be lost during fallow. A series of small rainstorms normally does not provide additional stored moisture under the fallow system unless moisture penetrates beyond the upper 20 cm. Most of the precipitation from a large number of light rainfalls is lost. However, even with the best practices, fallow is not absolutely efficient in storing moisture. In the North American Great Plains, the average amount of moisture conserved may not exceed 20 percent, while in the Pacific Northwest the figure has been estimated as high as 25 percent. In areas with 350-400 mm or more of rain, the release of nutrients during the fallow period may contribute as much to the increased yield of the immediate succeeding crop as the conservation of water.

Though the fallow system may lack efficiency, the additional small amount of moisture it stores in the soil has significant impact

on succeeding crops. A two-fold increase is not required to make the system economically acceptable since costs are substantially reduced. Cost reduction stems from a single harvest, planting, and period of plant care and fertilization. Generally, in a winter rainfall area receiving over 400 mm of rain, the fallow-cereal system is not recommended. Instead, a system of wheat/legume rotation may provide more satisfactory results.

In areas where rainfall is adequate to insure a crop each year with limited risk of crop failure, annual cropping may provide higher total production with marked reduction in soil erosion and better long term maintenance of soil productivity. Adequate use of nitrogen fertilizers, combined with adequate phosphorus and sulfur, become an essential part of any annual cropping systems developed.

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III. THE CHALLENGE FOR RAINFED AGRICULTURE IN NORTH AFRICA AND THE MIDDLE EAST

Some countries rely heavily on semi-arid winter rainfall zones for their grain and meat supplies. This is particularly true of developing countries in North Africa and the Middle East. In these nations grain production has barely been keeping pace with increased demand due to growth in population and income. Meat production, in contrast, has lagged far behind demand growth. To close the meat supply gap while continuing to provide cheap cereals for growing populations represents a serious challenge to agriculture in the rainfed zones.

A. Population, Income, and Growing Demand for Cereals and Meat

Dryland cereal and livestock production will play an important role in feeding the rapidly growing populations of North African and Middle Eastern countries. Table 1 presents population statistics for eight countries, selected because of heavy dependence on dryland farming. On the average, population in these countries grew 2.9 percent annually, from 1962 to 1976, compared to a worldwide growth rate of 1.9 percent. Table 2 illustrates that per capita gross domestic product--a measure of income--averaged 4.1 percent increase yearly for these same nations during the last half the sixties. Taken together, population and income growth determine the expected rate of increased demand for food, including cereal and livestock.

Assuming an income elasticity of 0.2 in the demand for cereals, and an elasticity of 1.3 for meat*; cereal demand would have grown at an estimated 3.7 percent annually in the later sixties and early seventies, compared to 8.2 percent growth in demand for meat. To avoid pressure for increased prices, or imports, production would have had to maintain these same growth rates.

* These are the estimated elasticities for Africa (excluding S. Africa) and the Near East, cited by John Mellor, The Economics of Agricultural Development, Ithaca, New York: Cornell U. Press, 1966. Mellor extracted his estimates from UN Food and Agriculture Organization, Agricultural Commodities--Projections for 1970, FAO Commodity Review Supplement, Rome, 1960.

Table 1 - POPULATION

Population Statistics for eight selected countries with extensive dependence on winter rainfall agriculture.

	Population 1962	Population 1976	Percent annual rate of population growth (1962-1976)	Percent of population in agriculture in 1976
	(millions)			
Algeria	11.2	17.3	3.1	54
Morocco	12.4	18.0	2.8	53
Tunisia	4.0	5.9	2.9	44
Iran	22.7	34.0	2.9	42
Jordan	1.8	2.8	3.2	29
Lebanon	2.2	3.0	2.4	14
Syria	4.8	7.5	3.2	49
Turkey	28.9	40.9	2.5	60
All 8 countries	85.9	129.4	2.9	50
World	3099.6	4043.3	1.9	47

Source: FAO Production Yearbook, v. 30, (1976).

Table 2 - INCOMES: GROSS DOMESTIC PRODUCT PER CAPITA

Per capita gross domestic product for eight selected countries, given in 1970 constant market prices, U.S. Dollars

Country	1965	1970	Average Annual Rate of Change (Percent)
Algeria	$260	$287	2.0
Morocco	211	233	2.0
Tunisia	235	239	0.3
Iran	282	385	6.4
Jordan	291	305	0.9
Lebanon	536	594	2.1
Syria	194	238	4.2
Turkey	359	447	4.5
All 8 Countries	294	359	4.1

Source: Arid Lands Agricultural Development Program, Selected Agricultural Statistics in Ranked Order for Countries of the Near East Region, Ford Foundation, Beirut, 1975 (mimeo).

B. Cereal and Livestock Production

Cereal production experienced a very uneven pattern among the eight countries represented in Table 3. Jordan and Lebanon endured net declines in cereal production between 1961-65 and 1974-75*; with

* Averages over several years were used for comparison, to eliminate the effects of annual weather fluctuations.

Table 3 - MID-EAST CEREAL PRODUCTION

Wheat and barley production in eight selected countries

	Average Annual Area Cropped (1,000 Ha.)					
	Wheat		Average Annual Rate of Change	Barley		Average Annual Rate of Change
Country	1961-65	1974-76		1961-65	1974-76	
Algeria	1,971	2,133[f]	-0.6	811	758*	-0.5
Morocco	1,578	1,840	1.3	1,627	1,991	1.7
Tunisia	1,002	1,108[f]	0.8	507	358*	-2.3
Iran	3,580	5,333[f]	3.8	990	1,431[f]	3.4
Jordan	249	159[f]*	-2.8	85	40[f]	-4.1
Lebanon	68	57*	-1.2	13	7[f]	-3.6
Syria	1,396	1,606	1.2	740	960	2.3
Turkey	7,959	8,906	0.9	2,791	2,621	-0.5
All 8 countries	17,803	21,142	1.4	7,564	8,166	0.6

	Average Annual Yields (kg/ha.)					
	Wheat		Average Annual Rate of Change	Barley		Average Annual Rate of Change
	1961-65	1974-76		1961-65	1974-76	
Algeria	636	794	1.9	587	718	1.7
Morocco	847	1,015	1.5	808	1,134	3.1
Tunisia	494	798	4.7	286	624	9.1
Iran	802	1,012	2.0	800	873	-0.7
Jordan	721	673	-0.5	735	501	-2.5
Lebanon	939	1,101	1.3	968	1,007	0.3
Syria	783	1,034	2.47	877	615	-2.3
Turkey	1,079	1,590	3.6	1,235	1,640	2.5
All 8 countries	892	1,222	2.8	913	1,155	2.0

	Average Total Annual Production (1,000 metric tons)					
	Wheat		Average Annual Rate of Change	Barley		Average Annual Rate of Change
	1961-65	1974-76		1961-65	1974-76	
Algeria	1,254	1,713	2.8	476	558	1.3
Morocco	1,337	1,873	3.1	1,315	2,279	5.6
Tunisia	495	880	6.0	145	220	4.0
Iran	2,871	5,394	6.8	792	1,263	4.6
Jordan	180	120	-2.6	62	22	-5.0
Lebanon	64	62	-0.2	13	8	-3.0
Syria	1,093	1,657	4.0	656	771	1.3
Turkey	8,588	14,137	4.9	3,447	4,310	1.9
All 8 countries	15,883	25,836	4.8	6,906	9,431	2.8

f = FAO estimate
* = unofficial figure

Source: Food and Agriculture Organization, Production Yearbook, v. 30, 1976.

the heaviest declines occurring in barley; both area and yield declined. Yield slumps could mean that cereal production was pushed onto more marginal lands, whereas area declines resulted (in some cases) when cereal lands were switched to irrigation or higher valued crops. War and social unrest undoubtedly had a hand in these trends. For the eight country group, however, cereal production increased at an overall annual rate of 3.8 percent with wheat outdistancing barley (Table 4). Yields rose much faster than crop area. Comparing the 3.8 rate of growth in output to the 3.7 rate of growth expected from changes in population and income, cereal production can be seen to have barely kept pace.

Table 4 - MID-EAST GROWTH

Average annual percentage rates of growth in population and income and in demand and production of cereals and meats, for eight selected countries[a/]

	Average Annual Percentage Rates of Growth in:					
Country	Population	Incomes	Cereal Demand	Meat Demand	Cereal Production	Meat Production
Algeria	3.1	2.0	3.5	5.7	2.5	3.8
Morocco	2.8	2.0	3.2	5.4	3.8	2.8
Tunisia	2.9	0.3	3.0	3.3	4.9	7.7
Iran	2.9	6.4	4.2	11.2	6.2	6.8
Jordan	3.2	0.9	3.4	4.4	-3.3	0.5
Lebanon	2.4	2.1	2.8	5.1	-1.5	-0.8
Syria	3.2	4.2	4.0	8.7	2.9	3.8
Turkey	2.5	4.5	3.4	8.4	3.4	3.6
All 8 Countries	2.9	4.1	3.7	8.2	3.8	2.7

[a/] Population figures are taken from Table 1 and cover the period 1962-1973. Income growth rates are from Table 2 and are based on averages for 1965 to 1970. Meat and cereal production growth rates are based on average changes between average annual production in 1961-65 and 1974-76, as shown in Table 3 Demand growth rates are calculated on the assumption of a 0.2 income elasticity of demand for cereals, and 1.3 for meats.

In contrast, the central dryland cereal production zones of the U.S. state of Oregon during the 10 years of 1964-66/1974-76 registered an average annual 9.5 percent increase in wheat production. However, the bulk of increase was due to release of acreage from acreage reserves. While yield rose 2.8 percent annually (Table 5), a rate of growth comparable to that for yields in North African and Middle Eastern countries, the 1974-76 average Oregon yield amounted to more than twice that of the eight developing Near East countries.

Livestock production performance for the same Near East developing countries is shown in Table 6. Again, substantial variation occurrs among countries. Overall, however, meat production from cattle increased at an estimated rate of 3.1 percent per annum, while sheep and goat meat output increased at a lower 2.7 percent. These rates fall lower than the estimated 8.7 percent overall rate in growth of demand for meat.

A comparison between the statistics on the average rate of meat

Table 5 - OREGON WHEAT PRODUCTION

Average wheat production in six selected counties of Central Oregon

	Hectares	Production (metric tons)	Yield (kg/ha)
1964-66	223,701	454,150	2,030
1974-76	339,936	885,756	2,605
avg. annual rate of change	5.2%	9.5%	2.8%

Source: Compiled by Extension Economic Information Office, Oregon State University.

offtakes* for the eight selected dryland countries (Table 6), and those for the U.S. and Australia (Table 7) requires caution. The U.S. cattle herd is managed to efficiently produce beef under relatively luxuriant conditions with extensive feedlot finishing and a majority of the cattle raised in the higher rainfall, temperate regions. Similarly, sheep in the U.S. are managed for profitable meat and wool production under conditions generally less harsh than in the eight selected countries.

In contrast, sheep in Australia are managed chiefly for wool production, and the meat offtake rate is low in comparison to the eight selected countries. The meat offtake rate for Australian cattle has been about half that for the U.S., but more than double that experienced by seven of the eight selected countries. It should be noted that recent offtake rates in Lebanon, for cattle meat, have been almost as high as those of Australia.

C. Trade in Cereal and Meat Products

There are several methods of balancing differences between production and demand levels. Buffer stocks are, of course, one way to meet differences associated with annual fluctuations in production, but storage cannot solve problems arising from sustained or growing shortfalls. Prices can be increased or some form of rationing or non-price allocation can be established. In most cases, however, countries rely on a combination of changed prices and trade to bridge would-be gaps in the longer run balance of production and demand.

International trade in cereals and livestocks exerts a great influence on the marketing of agricultural commodities and inputs in the dryland areas. Table 8 reveals that this trade has expanded substantially over the past decade or more. These data highlight the dichotomy between livestock and cereals. Net imports of cereals exploded between the early sixties and the early seventies, whereas meat trade (for the group of selected countries) shifted from an even balance to a slight net export position. Add to the production and demand data presented earlier--figures indicating that cereal outputs and increases in demand from growth of population and income

*Offtake: meat produced per head in indigenous herds.

Table 6 - HERDS AND MEAT PRODUCTION

Herd sizes and meat production in eight selected countries

Country	Average Herd Sizes (1000 Head)					
	Total Cattle[a/]		Average Annual Rate of Change (percent)	Total Sheep & Goats		Average Annual Rate of Change
	1961-65	1974-76		1961-65	1974-76	
Algeria	810	1,245[f]	4.1	8,130	11,520	3.2
Morocco	2,793	3,473[f]	1.9	17,445	22,867	2.4
Tunisia	562	860[f]	4.1	3,738	4,255	1.1
Iran	5,499	6,583[f]	-2.8	43,416	48,867	1.0
Jordan	61	39[f]	-2.8	1,344	1,252	-0.5
Lebanon	100	84[f]	-1.2	656	562	-1.1
Syria	456	547	1.5	4,703	6,517	3.0
Turkey	13,783	14,490	0.4	55,528	59,403	0.5
All 8 countries	24,127	27,321	1.0	134,960	155,243	1.2

	Average Total Meat Produced Annually From Indigenous Animals (1000 metric tons)					
	Cattle[a/]		Average Annual Rate of Change (percent)	Sheep & Goats		Average Annual Rate of Change
	1961-65	1974-76		1961-65	1974-76	
Algeria	17	28[f]	5.0	37	54[f]	3.5
Morocco	68	90[f]	2.5	55	74[f]	2.7
Tunisia	13	24[f]	6.5	22	37[f]	5.2
Iran	64	112[f]	5.8	150	209[f]	3.0
Jordan	1	1[f]	0.0	6	7[f]	1.3
Lebanon	2	4[f]	7.7	5	7[f]	3.1
Syria	13	12[f]	-0.6	41	57[f]	3.0
Turkey	180	230[f]	2.1	297	380[f]	2.1
All 8 countries	358	501	3.1	613	825	2.7

	Average Annual Rate of Offtake - Meat Produced per Head in Indigenous Herd (Kg/Head)[b/]					
	Cattle[a/]		Average Annual Rate of Change (percent)	Sheep & Goats		Average Annual Rate of Change
	1961-65	1974-76		1961-65	1974-76	
Algeria	21.0	22.5	0.5	4.6	4.7	0.2
Morocco	24.3	25.9	0.5	3.2	3.3	0.2
Tunisia	23.1	27.9	1.6	5.9	8.6	3.5
Iran	11.6	17.0	3.6	3.5	4.3	1.8
Jordan	16.4	25.6	4.3	4.5	5.9	2.4
Lebanon	20.0	43.7	9.1	7.6	12.5	5.0
Syria	28.5	21.9	-1.8	8.7	8.8	0.1
Turkey	13.1	15.9	1.6	5.3	6.4	1.6
All 8 countries	14.8	18.3	1.8	4.5	5.3	1.4

f = FAO estimate
* = unofficial figure
a/= in case of Turkey and Syria, figures include small numbers of buffaloes which are aggregated with cattle
b/= computed from data given above

Source: Food and Agriculture Organization, Production Yearbook, v. 30, 1976.

Table 7 - U.S. AND AUSTRALIAN MEAT PRODUCTION

Average annual rate of offtake*

	Cattle (kg/head)[a]			Sheep		
	1961-65	1974-76	Ave. Annual rate of change (percent)	1961-65	1974-76	Ave. Annual rate of change (percent)
U.S.	77.9	88.2	10.2	11.8	12.8	0.6
Australia	48.0	47.7	0	3.7	3.6	-0.2

[a] Based on data from FAO Production Yearbook, vol. 30, 1976.
*Offtake: meat produced per head in indigenous herds.

Table 8 - MEAT, CEREAL IMPORTS

Meat and cereal imports of seven[a] selected countries

	Average Annual Net Imports ($1000)			
	Live Animals, Meat and Meat Preparations		Cereals and Cereal Preparations	
Country	1962-64	1972-74	1962-64	1972-74
Morocco	-10	-2,428	90	109,197
Tunisia	6	6,567	69	37,614
Iran	-18	-6,181	180	368,535
Jordan	63	9,570	137	40,722
Lebanon	228	21,975	252	54,555
Syria	-28	4,510	-233	42,107
Turkey	164	-40,439	352	80,614
All 7 countries	77	-6,426	847	733,344

[a] Data not available for Algeria.
Source: Based on Food and Agriculture Organization, Trade Yearbook v. 29 (1975) and v. 19 (1965).

are increasing at roughly similar rates while population and income related meat demand increases are far outstripping increases in meat output--the fact that meat imports have not increased, and it can be deduced that strong upward pressures must have been exerted on meat prices.

Why do countries tend to import cereals and not livestock products? Why are cereal prices held at relatively low levels while livestock prices are allowed to rise? Answers to these questions are only speculative. On the one hand, live animals are relatively bulky and difficult to transport over long distances, especially where sea travel is involved. On the other hand, meat per se is highly perishable and requires expensive storage and handling facilities which are often not available in developing countries. Grains are cheaper and easier to ship and store. Furthermore, importing of grains often has been greatly facilitated by the concessionary commodity import programs which the more advanced countries offer to developing countries. Finally, there is the political factor. Upon

gaining independence or undergoing populist revolutions, developing countries in the Near East, as elsewhere, have placed a high priority on feeding their less advantaged multitudes. They have chosen to do this by keeping wheat and bread available in good supply, with prices low. Meat, which is generally perceived to be a luxury, has not received such favored treatment.

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IV. THE ECONOMIC FACTOR

A. The Farmer as Decision Maker

The primary decision-maker in dryland agriculture is the farmer. It is the farmer who has to change basic dryland farming practices to become more productive. This requires adoption of new techniques. Why is it that farmers in many dryland areas do not change their farming methods? Is it that they adhere blindly to tradition? Economists are inclined to believe that "traditional" farmers do not adopt new techniques and practices because it is not profitable to do so (T.W. Schultz, 1964). Others have observed that profit-seeking behavior may receive a lower priority than the avoidance of risk and uncertainty (Netting, 1974; Wolgin, 1975; Wiens, 1976). Also, government policies and institutions often distort the structure of incentives which determine what is and is not profitable.

Anthropologists and sociologists have identified a variety of ways in which non-profit-related factors and motives help explain traditional farmers' reluctance to adopt more productive practices (Cancian, 1972; Johnson, 1971; Salisbury, 1973). Some of these relate specifically to the drylands. For example, livestock raising may be valued as a way of life, in spite of characteristically low returns. Status and wealth may be gauged by the number of livestock owned, which, in turn, may explain why herd numbers are larger and individual animals smaller than strict attention to profitability would seem to dictate (Campbell, et al, 1976).

Traditional village societies may be quite powerful in terms of exacting compliance with established values and customs, such as egalitarianism and reciprocity (Brewster, 1967). Thus, new practices that are inconsistent with such values and customs may not be socially acceptable even though they are profitable on an individual basis. Furthermore, new practices typically imply inputs of both knowledge and production materials from the outside. This requires reliance on broadened exchange mechanisms, such as markets. Markets, however, can be difficult to develop in dryland areas due, among other factors, to relatively sparse populations and limited volumes of trade. In areas where markets are not well developed, profitability may provide only limited incentives. Land tenure institutions can also serve to modify the incentives which individual farmers and livestock producers face.

Cattle are held as a store of wealth (an end in themselves) by traditional societies in Swaziland, not only as a means of generating further income. The failure to recognize this has led to implementation of production-oriented livestock development programs, which may worsen the already serious overgrazing problem in that country (Doran, Low, and Kemp, 1979).

There are numerous reasons why it is not satisfactory to view profitability as the sole motivation for behavior. Nevertheless, time and again, profitability, wealth, and factors related to them have been shown to influence behavior. These are taken here as a starting place for explaining why farmers in the drylands behave as they do.

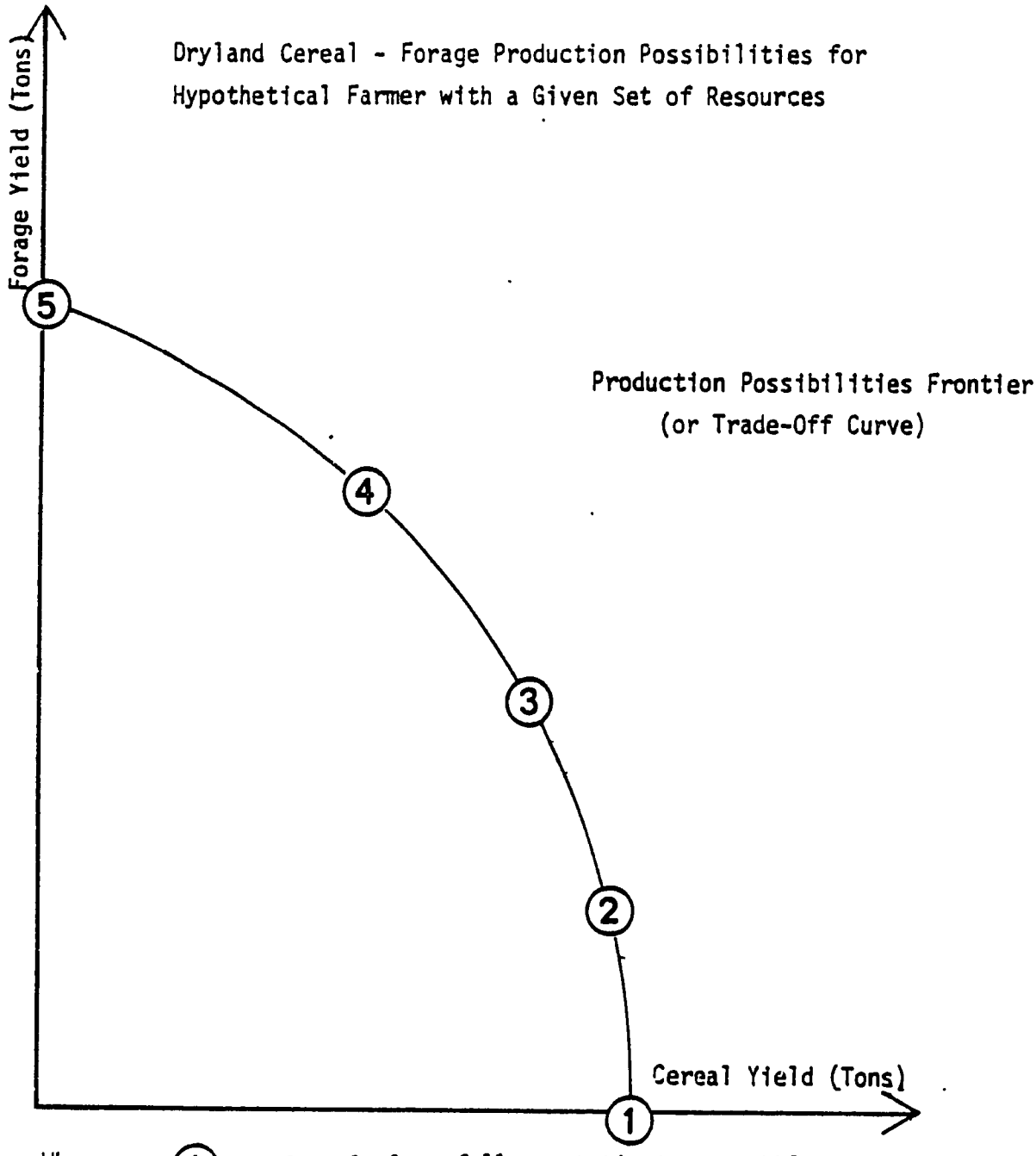
B. The Decision-Making Process

Although there is a common tendency to view him as just a cereals producer, the dryland farmer typically produces both cereal and forage crops. Even the cultivator who owns no livestock and who adheres strictly to the wheat-fallow rotation has wheat stubble which may be sold for grazing. Straw from grain crops also can be of considerable value for bedding, construction, fuel, and other purposes. In a recent study of Turkish wheat producers, for example, Somel found that straw was valued at about one-third the price of an equal weight of wheat (Somel, 1977). This relationship can be expected to vary among countries and between seasons. The cultivator also may choose to rotate forage and grain crops rather than to keep land fallow for a year between grain crops, or he even might decide on permanent pasture. As shown in Figure 1, he has a spectrum of grain and forage production possibilities from which to choose.

Consider a farmer with a fixed amount of land. Figure 7 depicts some of the trade-offs he may face in terms of various combinations of cereal and forage he could produce with his limited resources. At one extreme, hypothetically, he could produce forage for grazing and no other crop. At the other extreme, he may choose to produce only cereal crops and not allow the resulting stubble to be grazed. Numerous possibilities exist between the extremes for producing both forage and cereals.

The relative amounts of cereal and forage that a given piece of land can produce will differ among the various dryland subclimates, soil conditions, and terrains. In essence, different environments will cause the Figure 7 trade-off curve to be shaped and/or positioned differently. For example, temperatures in the Anatolian plateau of Turkey are probably too cool for extensive forage production during the winter months, while summers are mild enough and soils deep enough to carry over significant amounts of moisture into the fall wheat planting period, when land is summer fallowed. Hence, the curve for Anatolia would be positioned further outward on the cereal axis. In North Africa, on the other hand, hotter summers limit significant moisture carry-over from one crop year to the next. Since many forage crops grow well in the milder North African winters, it may make more sense to grow forage rather than to summer fallow in rotation with wheat. Thus, what is tech-

Figure 7 - PRODUCTION POSSIBILITES



Where:

1 = Cereal-clean fallow rotation; no stubble grazing

2 = Cereal-clean fallow, with stubble grazing

3 = Cereal-fallow, grazing on stubble and on weeds during fallow period

4 = Cereal-forage crop rotation

5 = Continuous forage crop (permanent pasture)

nically possible and what is profitable both vary among geographical areas.

While technical considerations may rule out certain production alternatives, there is often a wide variety of crop management choices within any geographical area. Options range between the so-called weedy fallow and clean fallow systems to choices among alternative cereal and forage species. Choices also encompass decisions on purchase of machinery, farm chemicals, or other inputs. These are typically cases where economics and considerations of profitability must be used in deciding which technique is optimal.

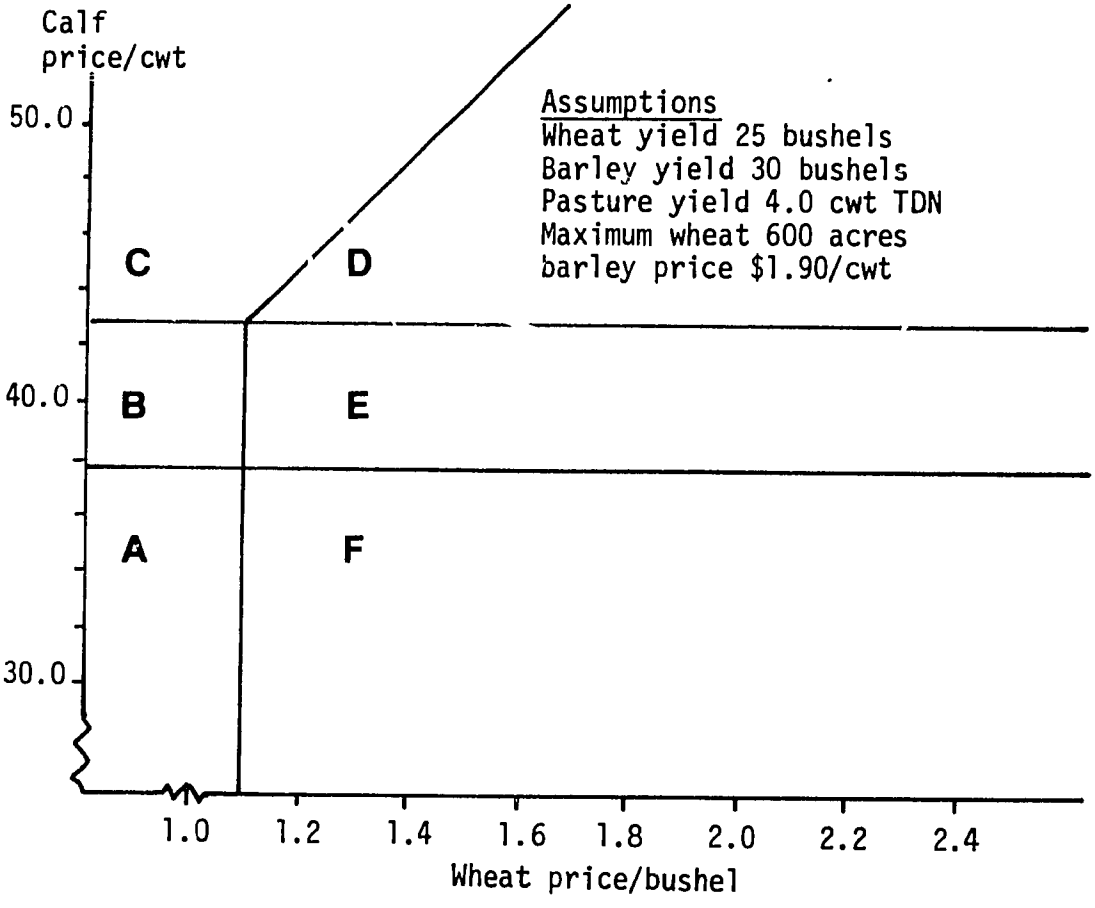
Studies conducted in Eastern Washington state (U.S.) by Weeks and Branson (1967) and Eastern Oregon (Gee and Stippler, 1967), examined some key aspects of combined livestock grazing and wheat farming. These studies each considered wheat farms of different sizes associated with rangeland of different sizes and cow herds of different sizes. Results indicated that the relative prices of wheat and cattle strongly influence the degree of complementarity of these two types of enterprises.

Other things being equal, an upward shift in the livestock-to-cereal price ratio favors production of more forage and less grain. A recent study (Gee 1973) examined trade-offs which would occur between forage and grain production (as the relative prices of calves, wheat, and barley change) in order to maximize profit for a 1600 acre wheat-livestock farm in the intermountain region of the Western U.S. Figure 8 illustrates how land would be allocated between wheat, barley, fallow, and pasture, depending upon their relative prices. Barley prices are assumed to be constant. In sector A on the chart (low calf and wheat prices) all land is devoted to a barley-fallow rotation. High calf prices depicted in sector C cause a complete shift to pasture. In sector D, with calf and wheat prices both high, wheat and pasture are produced, and wheat stubble is used for grazing.

In Figure 8 all factors except wheat and calf prices are held constant. Gee also developed a series of nomographs which permitted the incorporation of the effects of production cost changes and pasture productivity changes. Such a nomograph is shown in Figure 9. It takes a calf-wheat price combination lying above and to the left of any given pasture yield line before permanent pasture will replace wheat-fallow. In the example illustrated, with wheat at US$1.80 per bushel, calf prices of US$54.00 per hundred weight would be necessary before permanent pasture could profitably replace wheat, assuming a pasture TDN yield of 4.0 cwt per acre. At 7.0 cwt TDN pasture yield, substitution could occur at a much lower calf price of US$42.80. Side scales permit a shifting of the basic trade-off lines to account for the effect of changes in production costs. For example, if the cost of a beef cow is reduced by US$11.10 per head (3 units on side-scale A) a calf price of only US$50 per hundred weight would be needed before a shift to permanent pasture would increase the farmer's profits.

Figure 8 - WHEAT AND PASTURE

Price map for wheat and pasture on a 1600-acre dryland farm intermountain area



A Land Use
Barley 800 acres
Fallow 800 acres

B Land Use
Barley 636 acres
Fallow 636 acres
Pasture 328 acres

C Land Use
Pasture 1600 acres

D Land Use
Wheat 600 acres
Fallow 600 acres
Pasture 400 acres

E Land Use
Wheat 600 acres
Barley 61 acres
Fallow 661 acres
Pasture 278 acres

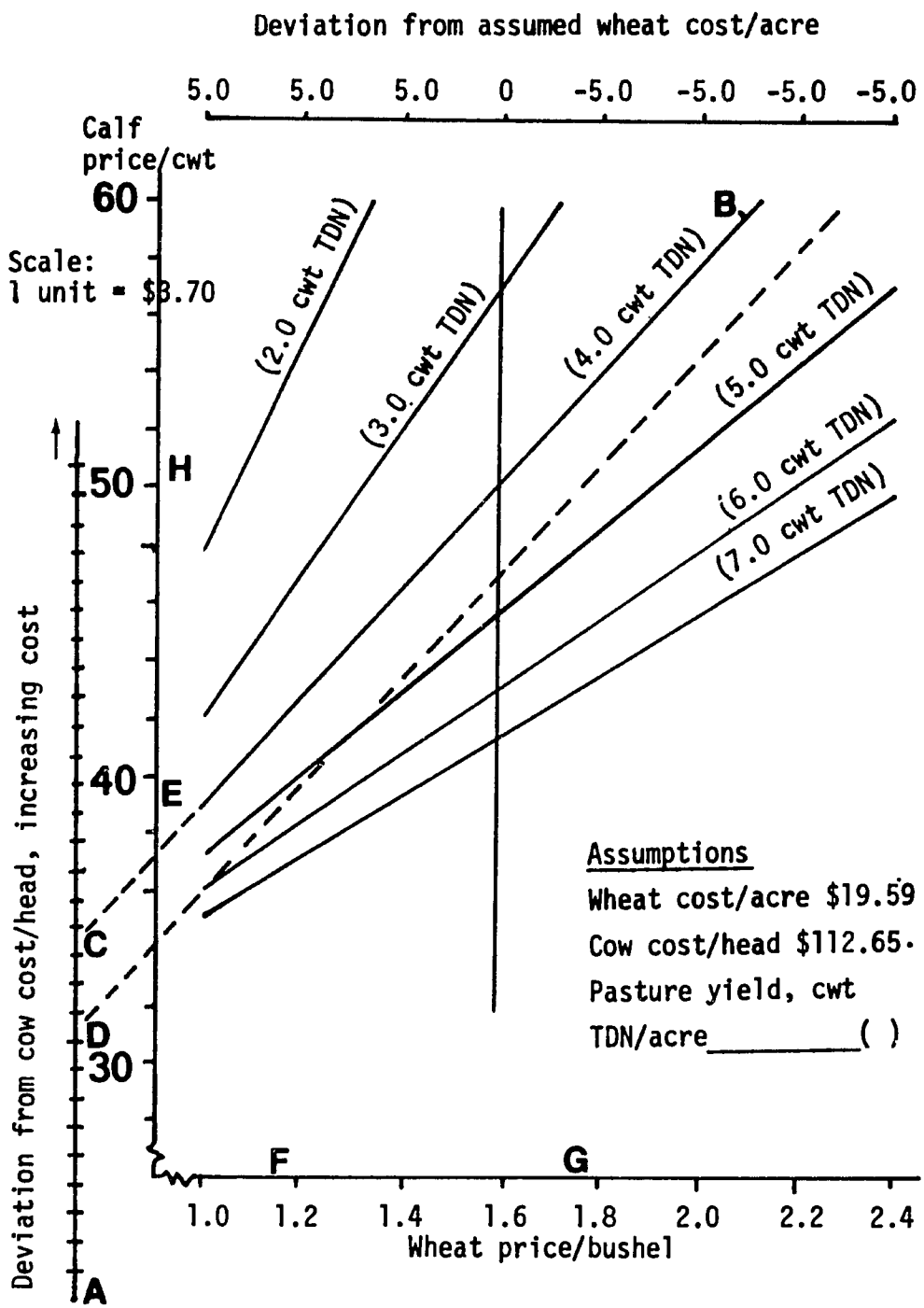
F Land Use
Wheat 600 acres
Barley 200 acres
Fallow 800 acres

Source: Gee (1973)

Gee's analysis is designed for a particular dryland area of the United States. Nevertheless, the basic principles apply to the drylands of the developing countries: different grain and forage-livestock combinations become optimal as the relative prices of livestock and cereals change. Furthermore, different farming systems are used to produce grain and forage as the prices vary.

Figure 9 - DRYLAND FARM WHEAT

Nomograph for wheat on dryland farms in the intermountain area, total shift to pasture, wheat yield 25 bushels.



Source: Gee (1973)

Other influences being equal, farmers can be expected to increase production of those goods for which prices increase. Evidence indicates that livestock prices are increasing more rapidly than cereal prices in the dryland countries. For example, Forder reported this to be the case in Turkey during the sixties, as shown in Table 9. Recent reports from Tunisia indicate that forage crop and livestock prices are both increasing relative to cereal prices in that country too*

Table 9 - PRICE INDEXES, TURKEY

Price indexes for animals, animal products and cereals in Turkey, 1964 to 1970

Year	Animals	Animal Products	Cereals
1964	111.1	102.1	100.9
1965	116.7	111.9	111.9
1966	126.5	121.7	114.7
1967	152.8	138.1	114.0
1968	148.3	133.6	119.3
1969	155.3	141.6	128.4
1970	179.1	150.0	131.1

Source: Forker, O.D. (1971b)

Reasons for increased livestock prices relative to those of wheat were mentioned in Chapter III. The implication for farmers is relatively clear: Conditions would favor his shifting to more intensive livestock production.

Product prices suggest only a partial explanation of the farmer's incentives, however. Input prices and resultant costs of production also play a role in determining which combination of products and farming systems a grower chooses.

Resource availability and costs vary from country to country and even among regions within a country. Low prices for a given input will favor the production of those products that are heavy users of that input. Livestock-forage production appears to be far more labor intensive than production of cereals. A recent survey of Australian livestock producers supports this contention. Farms in the low rainfall, pastoral zone attributed 33 percent of their production costs to labor, whereas those in the intermediate rainfall, wheat-sheep zone, reported labor as only 21 percent of total costs (see Table 10).

The same study demonstrated that farms in the high rainfall zones, where cattle tend to be confined in fenced pasture units, were not as labor intensive. Thus, farmers in the developing countries, where labor is more abundant and less expensive, are

* Personal communications with Ali Ben Said Selmi, Tunisian National Agricultural Institute, October 1976.

Table 10 - INCOME AND LABOR

Farm Income Sources and Labor Intensity in Three Agro-Climatic Zones in Australia

Zone[a]	Percent of Farm Receipts Attributable to				Percent of Total Farm Costs Attributable to Labor
	Cattle	Sheep	Crops	Other	
Pastoral	41	48	10	1	33
Wheat-Sheep	18	41	36	5	21
High Rainfall	40	42	11	7	24

[a] Roughly speaking, the pastoral zone in Australia is considered to have less than 200 to 250 mm of rainfall per annum, the wheat-sheep zone receives between 250-500 mm, and the high rainfall zone more than 500 mm.

Source: Bureau of Agricultural Economics, The Australian Beef Cattle Industry, Industry Economics Monograph No. 13, Canberra: Australian Gov't Pub. Service. 1975.

expected to place more emphasis on range livestock and forage production than dryland farmers in the advanced countries do, because of the relative labor cost advantage.

Livestock production becomes a means for small farmers to use low cost, surplus labor to generate income during slack periods of crop production. Perhaps more important, grazing livestock may represent the only means a farmer has of exploiting certain available resources such as common pastures, roadside weeds, and cereal aftermath.

The livestock/cereal studies mentioned above lend some valuable insights on questions of why production in the drylands is organized in the variety of ways that are observed. But, there are some questions which cannot be answered with the static models that were used. For example: with high levels of variation in prices for both grain and livestock, what would be the effects, over time of following one production strategy or another? Add to this the uncertainties of grain yields and animal performance due to highly variable weather conditions affecting crops and forages from year to year. The analysis of such a dynamic set of problems can be extremely complex.

Varied are the risks faced by the dryland farmers and herders in these complex environments. Yet most of the several million such people not only survive from year to year but pass down viable traditions for doing so.

There is a growing body of literature which integrates the knowledge of biologists, ecologists, and economists under the heading of systems analysis. Dynamic processes of system behavior are modeled explicitly, and the gaps in existing knowledge stand out more clearly than when viewed from the perspective of any particular discipline (See: Dent and Anderson, 1971; Spedding, 1976; Arnold and deWit, 1976; and Innis, 1978).

C. Strategies for Technical Change

Hayami and Ruttan's Agricultural Development: An International Perspective, stands as one of the most influential works in recent times focusing on the economics of agricultural development. It is dedicated to investigating the hypothesis that, in order to be successful, a new technology must utilize abundant resources and conserve those resources which are scarce. The authors amass a convincing set of evidence. For instance, Japan and Taiwan, historically labor abundant--with land and capital relatively scarce--both predicated successful development programs on bio-chemical technologies requiring increased labor inputs, but not massive amounts of large-scale capital equipment. However, both nations were quite successful at developing small-scale machinery (Johnston and Kilby, 1975). Techniques that use abundant--and therefore cheap--inputs and avoid use of scarce--and therefore expensive--inputs are naturally more profitable.

1. Mechanization

Tractor mechanization as a truly appropriate technical strategy for dryland farming continues to be the subject of debate. Opponents point to government policies which give preferential terms for importing tractors and soft credit terms to finance tractor purchases. They claim that tractor mechanization may be efficient, from a producer's viewpoint, only in the artificial economic environment created by such policies.

Proponents of tractors contend that they permit more thorough and timely farming operations than animal-drawn equipment, leading to a payoff in higher profitability. However, a thorough-going economic evaluation has yet to be conducted comparing the relative merits of various size tractors versus animal-draft cultivation in the drylands. A useful study would need to evaluate tractors and related equipment of various scales or sizes as well as improved animal-draft machinery; it also would need to incorporate prices corrected for exchange and interest-rate distortions.

Efficiency of resource use and profitability are only two considerations in technology-development strategies. Equitable treatment for all segments of society constitutes another important factor. Tractor mechanization may be seen as favoring large farmers, while causing small farmers to be further marginalized. Success with custom operation of tractors and combines in both Turkey and Iran counters this concern.* Small landowner-farmers often are able to hire tractor services; in other cases, small farmers have been able to purchase tractors and help pay for them by hiring out their services. Nevertheless, the possibility of big farm bias remains a continuing concern.

A country's mechanization strategy for agriculture can exert ripple effects throughout its entire economy. Not only are big

* For comments on custom hiring in Turkey, see Aresvik (1975) and Kapil (1973). For information on custom-hiring of combine services in Iran, see Izadi (1974).

machines capital intensive from the ownership point of view, but their manufacture tends to require far more capital intensive industrial facilities than does the manufacture of small scale and animal draft equipment. This, in turn, leads to the likelihood that larger scale equipment will have to be imported, thus creating an additional drain on scarce foreign exchange.* The need to import expensive fuel is also of concern to most countries. Thus, capital and foreign exchange requirements from aggressive mechanization strategies tend to multiply and can have negative ripple effects. Smaller scale mechanization can have beneficial ripple effects. There is more likelihood that small scale machinery can be manufactured in-country thus creating local jobs and reducing burdensome foreign exchange, for example. Small scale machinery tends to have less big farmer bias.

2. Farming systems

Selecting dryland farming systems poses several questions. Low rainfall areas, important for production of both cereals and forage-livestock, manifest two distinct strategies. Integrated farming emphasizing development of crops and livestock-forage within the same farming unit contrasts with programs that place more emphasis on specialized cereals and specialized livestock production units.

Oram (1956) emphasized the need to "...develop arable rotations which provide more fodder without detriment to cereal production...". At the same time he acknowledged that, "statistics clearly show how limited the success so far achieved in this direction has been." Spearhead for the current effort in the integrated farming approach is the CIMMYT (International Corn and Wheat Improvement Center, Mexico) program for introduction of medicago and subterranean clover varieties as forage in rotation with cereals in North Africa (Breth, 1975). Results from this approach have yet to be analyzed in economic terms, though preliminary data indicate that the system may not function as smoothly in North Africa as it does in southern Australia where it originated.

Management requirements for the system appear to be high in terms of both production control on the forage legumes themselves, and in controlling the animals grazing the legumes.** In Australia, the farmer planting the legume crop also owns and controls the sheep grazing it. That establishes an incentive not to overgraze since the farmer himself will bear the consequences. Furthermore, he maintains direct control of when sheep will be available for grazing, which can be extremely crucial in timing the flowering and seeding of the legume. In the North Africa situation, sheep often belong to nomadic tribesmen rather than the farmer, making it far more difficult for the farmer to control the extent and timing of grazing and the resulting effects.

Syria also has displayed active interest in developing

* For a full description of this process, together with case studies from Pakistan and Taiwan, see Johnston and Kilby (1975).

**To overcome the management problem many farmers in Australia reseed annually rather than depending and managing for natural reseeding.

cereal-forage rotations in some of its drier zones. A recent planning study for the Kamishly area in northern Syria, conducted by Washington State University (1976), provides some rough estimates of output value from various alternative rotations. Forage needs in these rotations would be met by vetch-cereal hay or possibly by clover or winter pea hay. The study indicated that a wheat-hay rotation would produce an average value of S.L. (Syrian pounds) 1136 per ha, compared to S.L. 1018 for wheat-fallow, for example. On the other hand, a wheat-lentil rotation would produce an average value of S.L. 2095 per ha. Unfortunately, cost data were not available for inclusion in the study, nor was it possible to account for any differences among the rotations in the value of stubble and crop aftermath for grazing.

3. Varieties and adoption

During the past decade, considerable emphasis has been placed on improving cereal production through introduction of high-yielding varieties. One line of reasoning behind this strategy appears to be that if yields are raised substantially, some land could eventually be released from cereals to shift back into forage production and permanent pasture for livestock. But adoption of new varieties has been slow, especially in the drier areas (Purvis, 1973; Aresvik, 1975; Demir, 1976; Gafsi, 1976; Perrin and Winkelman, 1976). Even the adoption of clean fallowing, mulching, and other improved techniques designed to raise yields of ordinary varieties has been far from universal (Wright, 1976).

The bulk of new cereal production technology currently being packaged for introduction in developing country drylands combines improved management practices, such as clean fallowing and more timely planting, with chemical and biological inputs such as fertilizers, herbicides, and genetically improved seeds. Programs in Turkey, Tunisia, and Jordan hold special interest. Adoption studies have been conducted in Turkey (Aresvik, 1975; Demir, 1976) and Tunisia (Gafsi, 1976). These reveal that high-yielding varieties adoption rates were substantial in some higher-rainfall coastal provinces of Turkey--in the neighborhood of 60 percent--but far less impressive for the drier Anatolian Plateau. Mann (1977a) recently documented encouraging increases in wheat yields for Turkey as a whole, but evidently these are not caused by any single technological element such as new varieties. Adoption in Tunisia also has been relatively slow, with only 31 percent of the farmers surveyed having adopted by 1972-73, some four years after the country's cereal improvement program began. While no figures are available for Jordan, adoption rates are apparently quite low.

According to Perrin and Winkelmann, these and other recent adoption studies demonstrate that:

> ... the most pervasive explanation of why some farmers don't adopt new varieties and fertilizer while others do, is that the expected increase in yield for some farmers is small or nil, while for others it is significant, due to differences (sometimes subtle) in soils, climate, water

availability, and other biological factors (1976, p. 10).

In essence new technologies may not be productive or profitable in every situation where they are introduced. Both the Demir and Gafsi studies support the contention that lack of adaptability to local environs hampers adoption. Both found valley farmers much more likely to adopt than hillside farmers.

A general observation hinged on the fact that most new crop varieties introduced in the dryland area of Turkey were bred under irrigated conditions and were spring varieties generally lacking winter hardiness for survival on the Anatolian Plateau.* Adoption rates were higher in coastal (compared to Anatolian) Turkey, where rainfall is abundant and Mexican wheat varieties prosper. Bezostaya, a high-yielding Russian variety, was adopted in the colder regions of Thrace and South Marmara where growing conditions did not suit the Mexican wheats.

Other factors were found to significantly affect adoption. Difficulty in obtaining new seed apparently limited adoption in both Turkey and Tunisia. Constraints on fertilizer availability curtailed its use in Turkey. Access to credit helped explain why some farmers failed to adopt high-yielding durum wheat in Tunisia. Adoption rates in Turkey were linked to education, whereas farming experience played a role in Tunisia.

Some of the disparity in findings of the Turkey and Tunisia studies by Demir and Gafsi arise because the same explanatory variables were not used in their regression analyses. Demir did not use a variable for experience, for example. Failures to establish the statistical significance of certain expected relationships in the two studies are as interesting as the cases where significant ties were found. For instance while using multivariate analysis which permitted the simultaneous control of many factors, neither study found a significantly positive association between farm size and rates of adoption. Yet, simple two-way classification of variables indicated that such an association existed in the Tunisian case. Gafsi's Tunisian study failed to establish any significant relationship between tractor cultivation and adoption of improved seeds, although in an earlier study of the Tunisian experience Purvis (1973) concluded that mechanization might be a prerequisite to success with new varieties.**

Adoption studies provide only circumstantial evidence concerning profitability although some direct evidence of the new cereals packages' profitability has been collected. Data from a 1967-68 study conducted by the Turkish Ministry of Agriculture (presented by Aresvik) compares net income from native wheats to those from Mexican wheats which were being introduced in Denisli province (1975, p. 167). Results showed that, on the average, net returns to land and management per hectare increased almost two and one-

* This situation is changing as new varieties are released from plant breeding programs in Turkey, Tunisia, and other countries.

**In his study of Turkey, Demir (1976) found tractor use to be a significant factor in new seed adoption in one of the three regions analyzed.

half times by utilizing Mexican seed and recommended practices associated with it.

A more recent study by Mann (1975a) compared farmers utilizing a package of recommended practices (fertilizer, herbicide, clean fallowing, and, in most cases, improved seed) with farmers utilizing more traditional practices in the Ankara area of the Anatolian Plateau. In this research net returns per hectare were almost doubled by utilizing the improved package.

Still unanswered is the question of why new practices--especially new varieties--have not been as rapidly adopted on the Anatolian Plateau as in Turkey's coastal provinces, given (apparently) comparable rates of profitability. One answer relates to the two studies not being directly comparable since they were conducted in separate years with differing cost and price structures. Also, the package of practices now advocated for the Anatolian Plateau by both the Ministry of Agriculture and Rockefeller Wheat Research and Training Center was unavailable in the region when the Coastal provinces started to adopt Mexican wheat. Mann's study may be an indicator that success is imminent.

A second study of new practices profitability on the Anatolian Plateau was conducted in 1975-76 by Somel and Mann, the year following Mann's initial study. Results of this later, more elaborate survey were reported in Somel's Ph.D. dissertation (1977). Sampled farmers were grouped into those using new practices and those not. Utilizing profit function analysis--quite a different procedure from the cost-return budgeting used in the earlier studies cited above--Somel could detect no significant difference in the profitability of the new practices versus the profitability of the old.

The contradicting studies present a quandry as to the adoption of new practices in Anatolia. Several possible explanations exist. In several ways, the later survey was more sophisticated. Sample farmers were chosen at random, rather than using data from a preselected group of demonstration farms. Profit function analysis allowed for more variability in farmers' choice of inputs, as well as for variation in prices and costs. Nevertheless, Somel felt the need to specify a criterion to identify farmers using the new practices; he used early plowing of fallow, perhaps an ineffective identifier.* Finally, it is possible that there was a climatic difference between the years surveyed. Weather, very favorable in Turkey during both years, was truly exceptional in 1975-76, the period of Somel's survey. This led Somel to suggest that perhaps true differences in new practices could be fully detected only in a normal year since many of the new practices--especially more timely plowing, clean fallowing, and weed control--are designed to conserve moisture.** Thus, their advantages would show up in years

* A more recent paper by Mann (1977b) shows that only 60 percent of fields which were plowed early received spring fertilizer and only 20 percent were planted with improved varieties. Thus, early plowing does not appear to be a very good proxy for the "new package" of practices as a whole.

**It is curious, however, that Mann's study (1977a) of trends in Turkish wheat yields concludes that the new practices have their greatest impacts in good weather years.

when moisture conservation becomes important.

None of the cited studies considers the interaction of forage-livestock and cereal production in determining the profitability of new cereal production practices. That omission could be a major shortcoming, based on the values of stubble and weedy fallow grazing. In general, new cereal technology packages ignore the need for forage and livestock production, a glaring weakness, especially in the case of small and medium-sized farms. Cereals alone fail to exploit all the resources (including labor and forage) available on these farms during certain times of the year.

The strategy for improving livestock production appears to be concentrated in introducing improved strains and crossbred cattle. In Syria, for example, a team from Washington State University recently observed:

> **Now a significant change is beginning to take place with most of the growth in the livestock sector being composed of high production European breeds of cattle imported for dairy and meat production plus imported breeds of poultry for both broiler and egg production. These new livestock enterprises are generating a totally unprecedented growth in the demand for produced concentrate and forage (1976, p. 40, emphasis added).**

The data in Table 6, which shows the relative improvement in cattle offtake relative to offtake from sheep and goat herds, coincides with this observation. Current strategies have overlooked the need to improve sheep and goat productivity, the livestock mainstay of drier areas, and to resolve the problems associated with traditional grazing of these animals on range and crop aftermath excusively.

D. Weather Variability, Profits, and Decisions

Differences in agro-climatic environment, subtle though they may be, need to be considered. Year to year variability in climate, especially rainfall, remains the single most distinguishing feature of dryland farming in the winter rainfall zone. It is this variability which determines, in large measure, the risks dryland farmers must take--risks above and beyond the price variability faced by all farmers (Bostwick, 1963).

Forker conducted a revealing analysis of variations in income from wheat production in Anatolia, versus that in the Turkish coastal zone. Table 11 summarizes his findings, and shows that a much greater proportion of variation in income can be attributed to yield fluctuations in the drier Anatolian region, compared with the coast. Furthermore, overall income variability runs much higher in Anatolia. The drier region, therefore, constitutes a more uncertain environment; the main uncertainty stems from yield variability influenced by meteorological variability, particularly rainfall.

Table 11 - INCOME VARIATION

Sources of variation in income per hectare from wheat production in selected areas of Turkey, 1950-1969.

Region	Percent of Variation[a] Attributable to Changes in Price	Yields	Gross Real Income Average	Variation[b]
			(TL/ha)	(Percent)
Anatolian Plateau Regions				
Central North	30	70	810	57
South East	20	80	688	54
Central South	22	78	754	42
Coastal Regions				
Aegean	60	40	878	15
Mediterranean	51	49	906	24
Turkey	41	59	777	30

Source: Forker, O.D. (1971a)

[a] Effects of time trends have been removed, and thus the figures estimate the relative importance of sources of year to year variance.

[b] This figure represents two standard deviations in variation, taken as a percentage of the overall mean income during the time period.

E. Land Tenure

Land tenure institutions determine who has the various rights and who makes the decisions associated with land. While these institutions vary considerably from country to country in the Middle East, a general pattern emerges.

Common ownership, property owned by nobody, but available to be used in any manner by everybody, has been a normal tenure form for a large share of the region's land. Ownership in common harks back to eras of abundant land in relation to very sparce populations. Where crop cultivation was concerned, an individual could take possession temporarily, but the land reverted to the common following harvest. This vivification of dead land was often the only way an individual was acknowledged to possess land (Campbell, 1977, p. 156).

In various countries, including Morocco, Tunisia, and Turkey, some lands eventually have come under group ownership and control by the extended family, nomadic tribe or clan, or by the village (Campbell, 1977; Carter, 1974; Aresvik, 1975). Other lands in many of these same countries have come under outright private freehold.

In situations where open, uncontrolled range exists--in cases of tribal or village ownership--and the land is merely vivified for use in cropping, resource use inefficiencies are likely to develop

because of associated externality problems.* Rangeland may be overstocked with livestock because the individual herder-owner is not forced to recognize the costs he imposes on others--greater distances to travel for forage, decreases in weight gain of their livestock--when he adds another animal to his herd and to the range. These costs are external to him since the other users have no right or basis to charge him for their loss.

In Turkey, village land management is a case in point. Village pastures are grazed in common by a herd composed of all livestock owned by village farmers. Common ownership leads to overstocking and overgrazing (Edwards and Conklin, 1973). Crop land, however, is owned privately by farmers, but it reverts to common grazing usage when not being cropped. If the grazing cattle cause weed problems--weeds perpetuated through livestock grazing can reinfest the next grain crop, use up soil moisture, and reduce the following crop's yield--the costs are borne by the owner of the field. Incentive to control cropland grazing evaporates, though crops may suffer a negative effect (externality).

Aresvik contends that fallow crop land used for grazing requires all fields in the immediate area be cropped in similar rotation so that they are available for grazing simultaneously. He claims this precludes individual farmers from introducing superior crop cycles since they would then violate the village flock's common grazing right (Aresvik, 1965, p. 132). However, Somel's 1977 study of farming in Ankara province discovered that farmers who plowed their lands early and removed a source of common grazing were not criticized by the rest of the community.

The trend in North Africa indicates gradual conversion of lands from common and tribally-held common range to privately owned cropland. In Morocco, Campbell found lands being continuously used (vivified) for cropping by the same individuals. "Subsequently, through a series of sales or legal transactions, the land acquired new legal status of melk (freehold) property," (1977, p. 157). Land devoted to permanent crops (such as olives) in Tunisia becomes recognized as private freehold.

Conversion to private property provides farmers with the incentives needed to improve land and with the security often needed to invest in machinery. However, conversion may impose external costs on stockmen who lose use of the land for grazing.

F. Marketing

Marketing institutions play a multifaceted role in dryland zones, areas prone to fluctuations of abundance and scarcity, both from year to year as well as during the annual cycle. These fluctuations result from variability of rainfall and yields from year to year, and from the periods of relative abundance and scarcity of moisture within the year. The natural function of a marketing

*For example, see H. Demsetz (1967).

system, then, is to help level these relative peaks and dips in food availability. The system includes: storage, from periods when commodities are abundant and thus relatively cheap, to times when they are scarce and thus relatively expensive; and, transportation from areas where food is abundant to areas where it is scarce.

Markets that function efficiently can significantly add to the overall performance of an economic system. Facilitating both the spatial and temporal exchange of goods increases the aggregate value of production. Goods transported to where they are relatively scarce become more valuable; the same applies when goods are stored until times of scarcity. Both grains and livestock experience spatial and temporal exchange in the drylands. Grains are stored and transported, both nationally and internationally, as are livestock, the latter being, to a great extent, self-transporting. The animals themselves store products of one season until the next. They also serve as a store of wealth in regions of undeveloped financial institutions.

Domestic trade and exchange of goods are old institutions among the farmers and herders of North Africa and the Middle East. Even though exchange may have taken the form of bartering rather than cash sale, forms of marketing have been significant to the life of the region; the subsistence farmer who grows virtually everything for his own needs has become rare, if not extinct.

Production specialization has, to some extent, been a necessary part of existence in the dryland areas. Extremely dry regions support only livestock production. Only oases or higher rainfall littorals can produce certain fruits and vegetables. Trading centers, ksur's, sprang up in North Africa as points of exchange between specialized producers. At the ksur, grains were exchanged for meat, meat for dates and olives, and so forth. The ksurs served not only as trading points for goods from distant locations but also as places for storing product from one season of the year to another.

Dryland trade has a natural periodicity and spatial movement that follows the weather. Roughly, the cycle operates as follows: in winter, when rainfall is occurring, crops are grown and range forage comes back to life after the dry summer. Herders move their flocks to more remote range areas for grazing. Crops and meat are generally in shorter supply and sell at higher prices. As summer approaches, crops are harvested and marketed, and grain prices drop. Range forage begins to disappear and herds move back toward more populated agricultural and urban centers where animals can graze on crop aftermath and also be marketed. Crop and livestock prices typically drop at harvest and with the onset of the dry season. An analogous cycle has been described by Shapiro (1976) (and is being documented) in summer-rainfall dryland areas of West Africa.

According to Jones (1977), there are three distinct indicators of how efficiently a market functions: 1.) Where markets are functioning smoothly, the spread between farm price and retail price should not be much greater than the sum of the costs of transporting and handling the crop as it moves from farm to consumer; 2.) The price of a commodity that has been held in storage for several months should also increase by about the cost of storage, but not much more; and, 3.) A third measure of performance is the extent to

which prices differ between markets and the extent to which they move together as conditions of supply and demand change. Jones also specifies the conditions which enable markets to function efficiently. These include adequate transportation and storage facilities; places where buyers and sellers can meet; information about quantities available, quantities needed, and when and where they are available and needed; and access to the market and its services on the same terms to all. Moderate costs of storage, shipment, and handling thus tend to facilitate efficient market operation.

Few, if any, studies exist which specifically measure the performance of markets in dryland areas. Shapiro's (1976) study of West African livestock marketing, for example, found surprisingly little evidence of arbitrage in cattle markets in two relatively close bush towns, thus indicating a low level of efficiency. He interpreted this as a sign of lacking marketing information. In a similar vein, the same study reported evidence of extremely high rates of return to investment in the cattle trade. Similar information for the winter rainfall areas would help assess marketing efficiency.

As noted previously, low marketing costs indicate efficiency. In contrast, marketing operations in the drylands can be expected to be relatively high cost. Long distances result in both high transportation costs and costs of information. Sparse populations suggest high road building costs. Finally, marketing facilities frequently will not be large enough to enjoy significant economies of scale. Comparative studies are needed to discern the effects of these influences on market efficiencies from area to area in dryland regions with winter rainfall.

G. National Policies

Governmental policies play a prominent role in the decision-making of dryland farmers. Governments control cereal prices in virtually every country. Livestock and meat prices also are controlled frequently, as are prices of key farm inputs. Controls undoubtedly distort incentives of farmers. In Tunisia, as an example, Gafsi (1976) found that the restrictiveness of controlled wheat prices had a significant negative impact on adoption of new varieties, since government channels represented the sole means of marketing new varieties. Gotsch (1976) showed that there was a relative decline in (controlled) wheat prices with respect to fertilizer prices in Jordan just as the new technology package (which included fertilizer) was being promoted. In his opinion the lowered wheat price had a direct bearing on farmers' failure to adopt the new package. Both Jordan and Tunisia have to contend with demands of relatively large urban and non-agricultural populations, which may help explain these nations' cereals pricing policies.

While price controls may be the most common agricultural policies, there is a wide variety of other national policies that impact on the farmer's decision to produce, on his decision to use productivity-increasing technology, and on the type of technology he chooses. If control prices are set at a level below equilibrium, they may act

both to discourage production and reduce the incentive to purchase new inputs. Wheat and bread being key staples in a nation's diet, the political pressure to control wheat prices is often strong. Price controls can benefit the farmer if floor levels are built in to prevent prices from dropping to damaging lows in years of good harvest. This is one means which governments can use to reduce production risks.

In many countries, governments intervene in key staples markets to the point that the government becomes the sole purchaser of the farmer's crop. Wheat stands as a case in point. Government purchasing may take advantage of a monopolistic position in the market and resort to noncompetitive purchasing procedures resulting in lower prices and reduced incentive to the producer.

Governments frequently manipulate foreign exchange rates in attempts to increase dwindling foreign exchange reserves. Many countries have tended to over-value their currencies relative to the

Table 12 - GOVERNMENT INVOLVEMENT, AGRICULTURAL OUTPUTS

Government Involvement in the Pricing and Marketing of Agricultural Products, Turkey

Commodity	Government Supports Purchase Price	Procures from Farmer			Domestic Sales			Municipality sets ceiling prices for consumers	Exports/Imports 1/	
		SEE	COOP	Private	SEE	COOP	Private		SEE & COOPs	Private
Wheat	X	X		X	X		X	X Bread	X	
Other cereals	X	X		X	X		X		X	
Pulses	X 4/	X 4/		X	X 4/		X		X 4/	X
Tobacco 2/	X	X		X	X				X	X
Potatoes				X			X			X
Sugar Beets 3/	X	X			X				X	
Cotton	X 4/		X	X		X	X		X	X
Oil Seeds	X 4/	4/	X	X	4/	X	X		4/	X
Opium Gum	X	X		5/	X		5/		X	5/
Vegetables		6/		X			X		6/	X
Fruits		6/		X			X		6/	X
Grapes		6/	X	X		X	X		6/	X
Citrus		6/	X	X		X	X		6/	X
Other			X	X		X	X			X
Hazelnuts	X		X	X		X	X		X	X
Pistachios	X		X	X		X	X		X	X
Dried Figs	X		X	X		X	X		X	X
Raisins	X		X	X		X	X		X	X
Olive Oil	X		X	X		X	X		X	X
Livestock		X		X	X		X		X	X
Meat		NA		NA	X		X	X	X	X
Wool				X			X			X
Tea 2/	X	X		X	X				X	

1/ All exports/imports are subject to some degree of control. A license must be obtained from the appropriate government agency.

2/ Tobacco and tea purchases and sales are made by the State Monopoly.

3/ The sugar company is a state economic enterprise that has the exclusive right to purchase, sell and export/import sugar beets and sugar.

4/ It is planned that the Soils Product Office will expand activities in pulses, oil seeds and livestock feed.

5/ Illegal private sector trade does probably exist.

6/ Procurement for export is now made by MEPA, a state supported enterprise, since 1969.

SOURCE: Forker (1971b)

dollar, or other international standards, resulting in reduced incentive for foreigners to demand the country's exports. Overvaluation acts as both a disincentive to domestic production and an incentive to import foreign goods. At times, imports of capital goods, such as tractors and other large machinery, are subsidized. Prices become distorted in favor of labor-displacing techniques which may be successfully adopted only by large, wealthier landowners.

Land reform and associated national policies may constitute disincentives to produce. Ceilings placed on size of land holdings after reform may be so low that efficient size production units become impossible. Typically, reforms are difficult to organize and administer, resulting in an extended time period for activation. Farmers with large or intermediate-sized holdings may wait years under the shadow of reform, not knowing if and when it will reach their property. Incentive to maintain former levels of investment and land improvement suffers in the face of uncertainty, ultimately cutting production as a result.

Ideologies may spawn reforms that attempt to establish new institutions. Difficulty in stimulating production is not an uncommon result. For example, Saleh (1975) observes that, when Tunisia eliminated its policy of requiring cooperative farming organizations between 1969 and 1973, the country's index of per capita agricultural production increased from 76 to 117.

Forker compiled a more detailed analysis of government involvement in pricing and marketing in Turkey. Table 12 shows the extent of government participation in commodity pricing whereas Table 13 depicts intervention in agricultural inputs.

Table 13 - GOVERNMENT INVOLVEMENT, AGRICULTURAL INPUTS

Government Involvement in the Pricing, Manufacture and Distribution of Agricultural Inputs, Turkey

	Government Sets Selling Price	Production or Manufacture		Distribution		Imports[1/]	
		Public	Private	Public	Private	Public	Private
Fertilizer	X	X	X	X	X	X	X[2/]
Compound Fertilizer			X		X		X
Certified Seeds		X	X	X	X	X	
Pesticides			X	X	X		X
Tractors	X	X	X	X	X	X	X
Combines	X			X	X		X
Other Farm Machinery			X	X	X		X
Feeds		X	X	X	X	X	

[1/] All imports are subject to some degree of control. A license must be obtained from the appropriate government agency. The purpose is to control the flow of currency.

[2/] Until 1971, private sector was permitted to import.

Source: Forker (1971b).

Rural credit policies frequently exhibit an anti-small farmer bias, a condition which both tends to reduce their incentives to produce and purchase new inputs, and to enhance the comparative advantage of large production units. Gafsi (1976) found that credit availability deficiencies in Tunisia reduced the rate of adoption of new varieties.

Table 14, taken from a recent study by Saleh (1975), presents a summary of policies currently in effect for Middle Eastern countries. Two countries surveyed have both price controls and import subsidies on wheat.

Oram (1977), in his keynote address to an international symposium on rainfed agriculture in semi-arid regions, stressed the vital role of incentives for innovation:

> "...Farmers must be provided with the incentives to innovate. This is particularly important in high risk environments, and in addition to manipulating production technologies and price ratios, consideration may need to be given to hazard insurance for small farmers or other guarantees against loss from adopting innovative methods. The link between technical research, micro-economic farm level 'constraints' type of studies, and policy making at the national level is often not strong enough to ensure that national planners are provided with the right signals on which to base decisions. This is essential if the undoubted opportunities for increased agricultural production in the semi-arid regions are to be realized."

The incentive structures and other features of the decision environments of small farmers, in development contexts, are catching the attention of more scholars. Focusing on these problems, two excellent compendia of papers have recently been published by the Iowa State University Press: Tradition and Dynamics in Small Farm Agriculture, edited by R.D. Stevens (1977); and, Economics and the Design of Small-Farmer Technology, edited by A. Valdes, G.M. Scobie, and J.L. Dillon (1979).

Anderson, Dillon and Hardaker (1977, p. 312) note that "formulators of agricultural policy will generally suffer 'fewer surprises' in program results if their economic models of farmer behavior include an adequate recognition of farming risks and farmers' attitudes toward them."

H. Farmers and Risk

Farmers' behavior toward risk falls into two general categories. Risk averters act to avoid or minimize risk by shunning activities perceived to have highly variable and uncertain results. For them the danger of possible loss looms larger than the benefit of possible gain. Risk takers in the opposite camp seek out high, but uncertain, gains.

Table 14 - PRODUCTION DISINCENTIVES

Disincentives to Agricultural Production by Commodity and Country

Country and commodity	Disincentives to agricultural production						
	Controls on producer prices	Controls on consumer prices	Non-competitive buying	Export control	Import subsidies	Restrictions on credit & land tenure	Restrictions on movement of agri. products
IRAN							
Wheat		X			X	X	
Rice		X			X	X	
Oilseeds & veg. oil		X			X		
Livestock, meat & milk		X			X	X	
JORDAN							
Wheat flour		X			X		
SYRIA							
Seed cotton	X		X	X		X	
Wheat and barley	X		X				X
TURKEY							
Wheat	X	X		X		X	X
Cotton							
Tobacco							
Livestock	X	X		X		X	X

Source: Saleh, Abdullah A., "Disincentives to Agricultural Production in Developing Countries: A Policy Survey," in Foreign Agriculture (special supplement) March, 1975.

Attitudes toward risk vary with income, age, and cultural environment. All small farmers or traditional farmers cannot be accurately stereotyped as being risk-averse. But logic supports the belief that small, low income farmers will tend to be more risk-averse since, living at or near subsistence level, they can ill afford the consequences of any losses.

Anderson (1974), and Anderson, Dillon and Hardaker (1977) have demonstrated the usefulness of "stochastic efficiency analysis" in aiding the identification of technologies that are not only more profitable on the average but are also less prone to low outcomes under unfavorable conditions.

Risk averters in a variable environment can be expected to produce at lower levels of output than under conditions of certainty (Whittlesey and Colyar, 1968). They also shy away from higher risk crops (Wolgin, 1975). In this vein, the mixture of traditional varieties in Tunisian wheat production provokes thought. Hyslop and Dahl (1970) show that durums occupied more than five times the area of bread wheats in Tunisia from 1949 to 1969, despite the fact that bread wheats out-yielded durums by over 50 percent (670 kg/ha versus 400). Several factors could help shed light on this phenomenon. Durums, as the key ingredient of couscous, are vital to the Tunisian diet. Also, Hyslop and Dahl discovered that the coefficient of variation for durum yields was only 22 percent, compared to 38 percent for bread wheats. The lower risk of producing durum may be why farmers opt to produce more durum and less bread wheat.

If risk averters shy away from crops perceived to have higher yield variability, they may understandably be more hesitant to adopt new technologies involving additional uncertainty due to lack of familiarity and past experience. Perhaps a lower anticipated variability, based on experience with traditional durum varieties, partly explains why Gafsi found Tunisian farmers adopting improved durums rather than bread wheats. Demir, in his adoption study for Turkey, found that new varieties were less likely to be adopted by farmers who felt they faced high weather risks.

Schmisseur (1976) conducted an analysis for several years of dryland farming project demonstration plots in Jordan. Yields from fields receiving recommended herbicide and fertilizer applications were compared to check plots. Test plots (only) were seeded with a grain drill and clean fallowed, while both test and check plots received the same seed. Yields increased an average 61 to 75 percent in three regions, over a four-year period starting in 1968-69. Yield increases for some of the years and regions ranged from nil to over 200 percent. Schmisseur observed that an adopting farmer would incur losses--adoption costs greater than returns--two out of four years in one province, and one out of four years in the other two regions. He concluded that many small farmers would find it difficult to take such risks.

Gotsch (1976) subsequently analyzed similar data from higher rainfall annual cropping areas of the same three Jordanian provinces. In this case, both test and check plots were drill-seeded and attention to tillage practices was not emphasized; thus, the improved practices package consisted only of chemical weed control and fertilizer. Gotsch felt that the way check plots were managed--utiliz-

ing some modern practices--would reduce favorable results from the new technology compared with crop-fallow demonstrations in drier areas. Instead, his data indicated that unacceptably low returns occurred in only three out of sixteen cases in the higher rainfall areas. He concluded that these results demonstrated the greater environmental suitability of improved technology for higher rainfall areas.

New technology can be made less risky by being simplified. The package approach, with interrelated practices and inputs, becomes a bundle of uncertainties for farmers to assess. There are cases where new technologies have been introduced piecemeal fashion. Mann (1975b) examined chemical weed control as a separate practice on the Anatolian Plateau. The increased yield value was more than four times control cost. He concluded that, "A large scale weed control program could provide the 'leading edge' for a campaign promoting use of the full package." More recently Mann (1977b) argued that new technology should be introduced in clusters of practices, with initial clusters being relatively simple and later clusters proceeding to more and more new inputs and more complex practices.

Returning to the success of durum production in Tunisia, Gafsi found that improved durum seeds caused a neutral upward production function shift, whereas the shift associated with new bread wheat varieties was not neutral. Benefits could occur from use of new durum seeds alone; benefits from improved bread wheat seed had to be accompanied by increases in other production inputs. Durum seeds represented a simpler and less uncertain package.

Two classic strategies for dealing with risk involve insurance and diversification. Farmers in developing countries typically do not have access to formal insurance policies. However, animals frequently play an insurance-like role by serving as a fall-back reserve in the event of crop failure (Netting, 1974; Gray and Plath, 1957; Holst and Schmisseur, 1979).

Diversification is a fancy word for putting eggs in more than one basket. Farmers diversify through a mixture of crops, seed varieties, and farming activities. Weather seldom affects two different crops identically; one crop will usually survive when another fails--all the better if price or yield fluctuations of one crop negatively correlate with fluctuations for the other. Wiens (1976) showed that negative correlations helped explain cropping patterns of Chinese peasant dryland farmers.

Producing both crops and livestock in the drylands also represents diversification. There is good reason to believe that in poor crop years stubble and aftermath may be more nutritious for grazing as more nitrogen available to the cereal plant collects in the leaves and stems. When cereal crops fail entirely animal grazing represents virtually the only means of recouping some of the loss (Noy-Meir and Orshan, 1977).

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V. SOIL, WATER, AND PLANT GROWTH

Moisture availability stands as a critical factor for successful dryland cropping. Moisture in the form of precipitation needs to be captured, stored, and conserved for use by crop plants during their growth cycle. The land--soil--becomes a moisture reservoir. Knowing some basic characteristics of the soil-plant-moisture relationship can lead to more effective dryland management levels.

A. Soil Particles

Particles, their size and manner of arrangement to form the soil matrix, determine the behavior of water in the soil. The primary particles composing soil range from a size of less than 0.002 mm to well over 2.0 mm along their largest, longest axis. The relative proportion of various size particles in a soil is usually reported according to the International Soil Science Society (ISSS) recommended classification. The ISSS system (Table 16) stems from a much earlier, rather arbitrary classification, but now has become the basis for all agronomic use, research, and development of soils.

Table 15 - SOIL CLASSIFICATION

Textural classification of soil fractions according to particle diameter

Range in diameter (mm)	Designation
> 2.0	gravel
0.2 - 2.0	coarse sand
0.02 - 0.2	fine sand
0.002 - 0.02	silt
< 0.002	clay

Analyzing soil physical and chemical properties begins by passing samples through a 2 mm sieve to remove larger diameter particles, referred to as stones.

The Atterberg system of soil classification (as adopted by ISSS) distinguishes between truly wet sand of 0.02 mm diameter and relatively dry sand of 2.0 mm diameter. This boundary was chosen to

separate coarse sand and fine sand. Particles with a diameter smaller than 0.02 mm can not be seen with the naked eye, and plant root hairs are not able to penetrate pores in soil material composed entirely of this size, or smaller, particles. This boundary was chosen to separate sand and silt. Colloidal particles with diameters smaller than 0.002 mm are subject to Brownian motion and form the lowest boundary to separate silt from clay. The ISSS scale is used for reporting percentages of sand, silt, and clay in a soil sample, data that help define physical and chemical characteristics.

B. The Soil Matrix

The soil particles are wedged together to form a tight fitting arrangement referred to as the soil matrix. Groups of primary soil particles may be joined together to form aggregates. Air spaces between the particles, the voids between the particles, are termed pores or pore spaces. Pore size distribution and spatial arrangement affects physical and chemical processes occurring in soils including water movement, root growth, exchange of gases between the soil and the atmosphere, and microbial activity.

In large pores, water is free to move downward by gravitational forces. These pores are important in soil drainage. Smaller pores retain water by capillary forces (making it less easily moved). Soil retained water and the degree of retention relate to the availability of water for plant growth.

Several soil characteristics can be measured easily and used in predicting soil behavior. These characteristics, labeled physical properties of soils, include particle density, bulk density, porosity, water content, degree of saturation, and soil water potential.

Density of a substance is defined as the mass per unit volume and usually relates to a homogenous substance. However, when dealing with soils, the term density describes the mass of solids in a given soil volume in its natural state. Air spaces are included in this volume. The density provides an indication of the degree of packing of soil particles. The greater the bulk density, the less air space there is in a given volume of soil.

The total soil volume includes the volume of solid matter plus void spaces. Soil density information derives from the proportions of solids and air in the total volume. Porosity, the term most frequently used to describe pore space, is defined as the ratio of voids volume to the total volume of the undisturbed soil.

C. Water

1. Properties of water

Water ranks as one of the most remarkable substances found in nature. It supports all life; no organism can live without water. Water's unusual and important properties derive from its molecular

structure.

A water molecule forms when two hydrogen atoms and one oxygen atom join together. Each water molecule becomes a dipole which reacts as a bar magnet. The positively charged hydrogens of water molecules are electrostatically attracted to the negatively charged oxygens in neighboring water molecules. Water molecules affinity to each other due to electrostatic forces, the hydrogen bond, produces a certain degree of order in the water. Water molecules join with each other to create a latticework providing water (as a liquid) some of its important properties. Because water molecules are not free to move totally independent of one another, water has a high viscosity. Water surface tension is also very high.

Water is nearly a universal solvent. Almost all inorganic substances dissolve in water and about half of all known elements are found dissolved in water. Without this ability to dissolve foreign matter, nutrition of plants could not occur. The roots of plants could not absorb nutrients from the soil.

The attraction between water molecules described as the hydrogen bond is also referred to as cohesion. A similar interaction exists between water molecules and the molecules of other substances, or adhesion. Water molecules can attach themselves to the molecules of substances such as soil particles. Almost any solid that has oxygen molecules in it attracts the hydrogen molecules of the water. The nature of the attraction is similar to the hydrogen bond.

Capillary phenomena occur in the cell walls of plant leaves, stems, and roots, as well as in soil pore spaces. This provides a continuous path of water from soil to leaf. The attraction of the water molecules for each other sustains the capillary columns. Capillary rise of water occurs in some pores when there is free liquid water within a few feet below. This does not occur in semi-arid soils which become moist to depths usually less than one or two meters; the underlying soil remains dry.

2. Soil retained water

The total amount of water in the soil exceeds the amount available for plant growth. A high clay content soil withholds more water from plants than a sandy soil. Water tends to move from sandy to clay soils if the two are in close contact and at the same water content. Since the soil water content is not a direct measure of the amount available to plants, another parameter, soil water potential, is used.

Soil research utilizes this index (soil water potential) to identify how strongly water is retained by soil at various water contents. At a water content of 20 percent, soil water potential often equals 0.19 bars or maximum availability in fine sandy soils, but might approach 15 bars or wilting in a clay soil. Thus, water in the sandy soil, but not in the clay soil, is available for plant growth.

Plants utilize suction to obtain soil water. When the soil retention suction--soil water potential--overcomes plant suction, water

ceases to move into the plant and wilting results. At the stage where plants wilt permanently, water content of the soil is said to have reached the permanent wilting point. The permanent wilting point percentage can be defined as: the percent of water present in soil when permanent wilting occurs.

Permanent wilting usually takes place at a soil water potential of 15 bars. However, permanent wilting, an estimate of average soil water content surrounding the plant roots, can occur when soil suctions some distance from the roots exceed 15 bars.

Soil field capacity refers to the amount of water remaining in soil after gravitational water has drained away and the water's downward movement rate has become very slow. The field capacity concept came about as a measure of the upper limit of water available in the soil for plant growth.

D. Moisture Storage

Shallow soils (less than 75 cm deep) limit moisture storage, especially in areas with long, dry summers (over 100 days) and daily average maximum temperatures that generally exceed 30°C. This limitation is critical in selecting a cropping system. In most winter rainfall areas where moisture is limiting, 75 percent or more of the rain falling during the winter following a crop can be stored in the soil if storage capacity is adequate, if infiltration rates match or exceed precipitation rates, and if the soil is not frozen during snow-melt runoff.

During the second year, a smaller percentage of the moisture that falls becomes stored soil water; this limits the efficiency of the summer fallow system. For environments in which the advantages of summer fallow, such as earlier emergence of fall wheat planted in moist soil, and the percentage of total moisture required for crop maturity are minimized, annual cropping systems permit a larger percentage of soil moisture to be used by plants.

Regardless of amounts of stored soil moisture following the winter season, there is continual moisture loss through evaporation during the summer. Rate and amount of loss depend on the evaporation gradient and length of the summer dry period. A long, hot, dry summer allows relatively little moisture to be stored in shallow soils (less than 75 cm) underlaid by an impervious soil or rock layer regardless of the amount present in the soil as the growing season starts.

Optimum storage of soil moisture with the summer fallow system of farming occurs where soils are over 1 m deep, preferably 1.5 to 2.0 m; where there is a limited number of days during the summer, or fallow, season with temperatures above 30°C; and where there is not enough rainfall to fill the soil moisture storage capacity with one winters' rainfall. Little advantage in soil moisture storage is achieved in areas where the normal is achieved in areas where the normal winter rainfall and infiltration rates are greater than the capacity of the soil to store moisture.

There are situations where maintaining moisture in the seedbed so that a stand can be established with the use of a deep furrow drill before the fall rains justifies a summer fallow operation. However, this cannot be done in areas with extended periods of hot, above 30°C, dry summer weather.

Soil erosion is a more serious problem and more difficult to control with the summer fallow system of farming. Growing a crop each year provides ground cover for a greater percentage of the time and adds crop residue each fall as the winter rainy season approaches.

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VI SOIL FERTILITY

Arable land in North Africa and the Near East has been farmed for centuries. Sloping land has suffered varying degrees of erosion. Crop residues needed to maintain desirable soil organic matter levels have been utilized for livestock feed. Depleted soils and the lack of fertilizer rate as two major factors limiting crop yields in many dryland regions. By contrast, fertilizer usage has made significant contributions to yields in more developed dryland areas.

Initial fertilizer costs plus fees for transportation from seaports to inland farming regions generate a drain on credit requirements and balance of payments. Ewell (1974) and Hauser (1974) have emphasized that costs and availability often cause fertilizer use to be one of the last items adopted in packages of new practices to improve crop yields.

A. Major Nutrient Needs

Nitrogen (N) and phosphorus (P) have been identified (Ahn, 1977; Wright, 1977) as the most important nutrients limiting yields throughout North Africa and the Near East.

Ammonium sulfate (24 percent S) and single super phosphate (10 percent S) have been used as sources of nutrients in many of the earlier fertilizer experiments so that S deficiencies have not been identified in all areas where low S could be a problem for plant growth. Ahn (1977) pointed out that S deficiency became evident in many areas of the Sahel when use of N and P fertilizers carrying S was reduced or discontinued. Sulfur deficiency is widespread (Beaton and Fox, 1971) throughout countries with intensively developed agriculture where S-carrying fertilizers are not applied and where S from industrial fumes is not added to soils in rainwater.

Rates of S required are relatively low for cereals; an N/S ratio of approximately 14/1 serves adequately for many crops (Beaton and Fox, 1971). Reductions in yield from applying more S than the crop needs are almost never observed. Thus, the cost of including S in the fertilizer program is low. Essentially, there are no risks of yield reductions in dry years. The possibility of S deficiency should be recognized wherever N-P fertilizers are used

that do not carry any sulfur.

Heavy metal micronutrients--zinc (Zn), manganese (Mn), and iron (Fe)--undoubtedly will be insufficient in many soils when crops that are susceptible to these deficiencies are produced. The Turkish Soils and Fertilizer Research Institute has identified these deficiencies for many citrus plantings in Turkey. However, these deficiencies are not likely to occur on wheat or barley until the major nutrient deficiencies are eliminated and higher levels of management are achieved. Zinc, Mn, and Fe deficiency could be a more immediate problem for corn or sorghum crops.

B. Current Dryland Practices

Information available in 1976 for North Africa, Turkey, and Iran indicated that very little P, or other fertilizer, has been used for production of dryland cereal crops in Morocco, Algeria, Syria, Iran, and Jordan. However, use of P and N-P fertilizers has increased in Turkey and Tunisia, especially on the larger farms where more capital has been available to adopt improved management practices.

1. Fertilizer use

Habib* indicated that fertilizer experiments must be located on the smaller farms in Tunisia to be sure of measuring responses from P. Soil tests for P indicate (Ulgen*) that large responses from P are not anticipated for wheat grown on some fields of state farms and adjacent village lands on the Anatolian Plateau of Turkey where fertilizer use has been accepted for some time. Ahn (1977) has noted that residual carry-over of P is evident in Sahel zone field work.

In developing countries, most of the fertilizer applied is in the ammonium (NH_4) form. Ammonium sulfate, urea, ammonium phosphates, and ammonium nitrate are the most widely used sources. Ammonium form of nitrogen offers certain advantages and disadvantages.

Ammonium nitrogen forms are not subject to leaching or denitrification. Therefore, the following year's nitrogen requirement can be applied during late fall in areas with cold winter temperatures (below 7°C) thereby reducing biological conversion of ammonium to nitrate nitrogen and consequent leaching. A disadvantage for these materials is that they supply the ammonium form of nitrogen which volatilizes when broadcast (and left) on calcareous soil surfaces. Urea presents a more serious ammonia volatilization problem than other nitrogen sources. Volatilization of nitrogen from any ammonium nitrogen source on the surface of calcareous soils occurs as:

NH_4^+ ammonium + H_2O + $OH^- \rightarrow (NH_4)_2CO_3$ (ammonium carbonate)

$(NH_4)_2CO_3 \rightarrow NH_3 + NH_4HCO_3$ (ammonium bicarbonate) or

$2\ NH_3 + CO_2 + H_2O$

*Personal communication

Ammonium carbonate is unstable and reacts to form volatile ammonia (NH_3) and ammonium bicarbonate.

Ammonia (NH_3) volatilization can be a serious problem throughout North Africa, Turkey, and the Near East where essentially all soils are calcareous and where ammonium or urea forms of nitrogen are used.

2. Crop residue effect on nitrogen requirements

The use of crop residues is an important part of soil management practices in dryland wheat producing areas. Crop residues act as a mechanical barrier to reduce soil erosion from both wind and water. Incorporation of crop residues into soil and the decomposition that follows maintains levels of soil humus (Hoerner, 1960), aids soil aggregation, and improves physical condition. However, the decomposition of cereal crop residues by soil microorganisms generally uses some nitrogen that would have been available to produce the next crop. This is especially true when the crop residue is undergoing decomposition while the crop is growing. An estimated 1 kg of nitrogen from soil or added crop residue is used by the microorganisms in converting 100 kg of crop residue to humus.

This phenomena explains the initial increase in nitrogen requirements frequently observed as new soil management practices are adopted. After a few years of increased fertilizer and crop residue use, the nutrients released from humus, plus residual carry over, can be expected to offset this nitrogen requirement (Brady, 1974; Broadbent, Bartholomew, 1965; Pesek et al., 1971; Russell, 1973; and Tisdale and Nelson, 1975).

C. Fertilizer Needs

There are four major methods for identifying individual nutrient deficiencies: grower application of fertilizers followed by visually observed deficiency symptoms; field research experiments and demonstrations; soil analyses for individual nutrients where field calibration data is available; and, chemical analyses of plant samples to evaluate levels of individual nutrients present in plants.

Identifying fertilizer needs logically begins with observation of results from grower application of fertilizers. Where fertilizers have been used, growers can provide an assessment of the economic benefit received for the money invested in fertilizer. Growers may not be able to identify an optimum rate or combination of nutrients, but almost always know if a given material has increased yields with the method of application used.

Scientifically designed field experiments and demonstrations with different nutrient rates constitute reliable tools to identify fertilizer response and essential components of any agricultural improvement program. Field research and demonstration programs provide response data that establish the relationship between response from individual nutrients, such as phosphorus, and a soil analyses value for phosphorus. For example, response data obtained in Turkey and Tunisia indicates a wide range of phosphorus response from areas with previous fertilizer use. Under these conditions a soil test most

efficiently extends fertilizer experiment data to fields that cover a range of previous phosphorus fertilizer history or a difference in original phosphorus level.

Preliminary calibration data (relationship between a soil test value and response from a nutrient) can be obtained from field experiments in the U.S. and Canada where soils have similar clay minerals and soil pH levels. However, some refinement and adaptation of this information to prevailing conditions must be made under local environmental conditions.

Chemical analyses of plant samples can provide a sound basis for evaluating and identifying soil fertility and plant nutrition problems (Martin and Matocha, 1973). In fact, this technique may surpass soil analyses for accurately assessing the level of all nutrients related to plant growth. Critical nutrient levels established for plant samples are relatively constant over a wide range of climatic conditions for a specific crop. Therefore, this technique can be used in development programs over a wider range of conditions than soil test values. A specific plant part, i.e., a leaf blade, must be sampled at a designated stage of maturity to obtain information that can be compared with results from other experiments. Also, a complete plant analysis that includes all nutrients affecting plant growth should be completed since extreme levels of one nutrient can have marked effects on uptake of other nutrients.

D. Soil Testing

Experiences in Turkey and Tunisia emphasize that, as fertilizer use increases, soil testing programs will need to be established to measure residual P and nitrate N mineralized during summer fallow. Moreover, soil testing and soil chemistry training should be an essential part of training programs.

Development projects in South America sponsored by the U.S. Agency for International Development and staffed by North Carolina State University have shown the practicality of establishing soil testing laboratories in developing countries (Fitts, 1976).

Research programs throughout the world have used procedures for extracting nitrate (NO_3) nitrogen from soils with water or a weak salt solution. Relatively uncomplicated techniques exist for measuring nitrate nitrogen or total nitrogen in such solutions. It is known (Bremner, 1965) that other salts, especially chlorides, can cause errors in colorimetric measurement of nitrate nitrogen. Conversion of nitrate nitrogen to ammonium nitrogen by a measuring this form of nitrogen by a standard Kjeldahl procedure takes more time, but is less subject to errors. In either procedure, accumulations or very low levels of "available" or nitrate nitrogen can be identified and used as a basis for adjusting nitrogen fertilizer recommendations.

Calcareous soils throughout most of the Near East and North Africa reduce the solubility of soil phosphorus by formation of di- and tri-calcium phosphorus. The sodium bicarbonate procedure

developed by Olsen et al. (1954) is widely used (Thomas and Peaslee, 1973) to extract phosphorus from calcareous soils. The solubility of phosphorus, and thus, its availability to plants, is dominated more by the chemistry of carbonates in calcareous soils than by the clay minerals present. This simplifies extracting a phosphorus fraction from calcareous soils that can be related to phosphorus response in field work.

The widespread use of these two soil test procedures provides a basis for starting a soil testing program in regions of marked deficiencies, or where moderate levels of soil phosphorus availability can be identified with a minimum of field calibration experiments. Extension-demonstration field programs with a limited number of fertilizer treatments can extend and confirm calibration information developed in other areas. More sophisticated soil chemistry and soil fertility research projects can follow as agricultural development and other research programs advance.

E. Application

Experiments and demonstrations should be conducted for various soil depths and rainfall regimes to establish optimum nitrogen and phosphorus application rates. Optimum nitrogen application is critical in dryland wheat production. Under normal conditions, approximately 4 kg of nitrogen will produce 100 kg of grain yield. However, excessive nitrogen may stimulate vegetative growth and delayed maturity of wheat overtaxing the available moisture supply. Yield can level off or even be reduced. Nitrogen applications must be geared to available soil moisture.

One model has been developed in the U.S. Pacific Northwest (Leggett, 1959) that relates nitrogen fertilizer requirements to available moisture and yield potential. Similar relationships have been established for other climatic areas (USDA Soil Scientist, 1974). Two equations have been developed, one for moisture and one for N:

With -

y = yield in kg/ha
N = nitrogen in kg/ha
M = moisture in mm/ha
SM = available soil moisture April 1st
X = yield produced from N during growing season
R = anticipated rainfall from April 1st to crop maturity
Y from moisture = 1 metric T/ha (SM + R - 100 mm rainfall)/ 65 rainfall or moisture
Y from N = 21 kg/ha (soil nitrate N + fertilizer N in kg/ha)

The 100 is subtracted to compensate for moisture, about 100 mm required to develop a plant with the potential to head. Wright (1977) has estimated that 135 mm of water is required for a wheat plant to produce heads in central Turkey.

The model was refined to show differences between stored soil moisture and late spring, or early summer rainfall:

Y in metric T/ha (from moisture) =
(1 metric T/ha/70 mm Sm + 1 metric T/ha/54 mm rainfall)
Metric T/ha (moisture) = 1 metric T/ha/70-10 + 1 metric T/ha/54 mm rainfall)

This equation shows greater yield potential derived from growing season rainfall than from stored soil moisture. The cooler weather associated with rainfall during the growing season probably contributes to the greater efficiency from growing season rainfall.

There are at least three factors that affect the amount of yield produced from a specified amount of water under different climatic conditions: evapotranspiration rates during the growing season obviously affect efficiency; percentage of crop-used moisture that occurs as rainfall during the growing season affects efficiency; and, period during growth of the wheat when moisture and temperature stress occurs. Moisture stress has greater adverse affect if grain is in the milk or soft dough stage of maturity. Yield can be either improved or destroyed during the short period of the plant cycle when hot winds and moisture stress have a critical impact.

If yield potential from moisture can be determined with reasonable accuracy, the nitrogen and other nutrients required to produce that yield potential can be estimated. Calculating yield potential from moisture is the most critical part of this model. Abundant moisture (unless there is flooding or abnormally heavy rainfall) will not reduce yield. However, if yield potential from moisture is overestimated (e.g., when growing season rainfall does not occur) and excessive nitrogen applied, the problems mentioned earlier will occur; the crop "hays off" and yields are reduced. The risk of yield reductions in years with below normal rainfall has caused many farmers not to gamble and add nitrogen to maximize moisture in normal years.

For wheat plants, there are three nitrogen sources available that must be considered in the nitrogen yield equation ($Y = X + 0.35$ (soil NO_3-N + fertilizers)). The first (N_1) is residual, or nitrate nitrogen released during the summer fallow period, that is available at the time of planting the winter wheat; the second (N_2) is nitrogen released during the growing season; and the third (N_3) is nitrogen as fertilizer.

Agronomists recognize that weed-free summer fallow has two primary functions: storing moisture for the following crop, and providing an incubation period for breakdown of soil organic matter (humus) by microorganisms and release of N, and to some degree S and P. There can be residual carryover of N from previous crops in addition to the N released from soil organic matter during summer fallow.

In areas with 350 mm of rainfall or less, nitrogen leaching or denitrification seldom presents a problem; ammonia volatilization can be avoided by applying nitrogen fertilizer at, or before, planting and mixing it into the soil to minimize these losses.

In heavier rainfall zones, or where precipitation is more concentrated in three or four winter months, late winter applications

of urea during cool temperatures can utilize rain to carry the urea into the soil and out of volatilization range. Because urea is quite soluble and endowed with a very weak charge before hydrolysis, it can be moved into the soil by rainfall before the hydrolysis occurs.

The ideal time to apply nitrogen varies with nitrogen source, winter rainfall amount, winter temperatures, and soil pH.

Adequate P will insure optimum yields, maximum root system development, soil moisture uptake, and early maturity. One to two week earlier maturity may allow the crop to escape some moisture stress that will occur during dry summer weather.

The possibility of reducing winter wheat or barley yields by P fertilization has been discussed among research workers from Australia, Canada, and the United States.* Apparently there are very few situations where yields of dryland wheat or barley have been decreased by adding moderate to moderately high rates of P. Thus, unlike N, the risk from adding excessive P is minimal even in dry years.

Fertilizer application of N, P, or any nutrient, requires the farmer to gamble that yield increases can be marketed at a price that covers costs and provides a profit. However, yield increases from fertilizer application are not assured. Growers do not have positive means of identifying fields for which fertilizer will increase yields, nor is there data to indicate the optimum application rates to achieve possible yield increases. Testing soil for N and P can reduce uncertainty and identify individual fields that probably will not respond to these nutrients. Alluvial soils, soils with less erosion, fields with previous P application, and the few cases where animal manures have been applied can result in adequate soil levels of P. Since P is relatively immobile in soils, P fertilizer not used by the crop in years with low rainfall remains in place to increase future crop yields.

All phosphorus fertilizers should be applied at pr before planting when they can be mixed into the soil or layed down as bands close to the crop seed. Phosphorus broadcast after planting remains on the soil surface where plant roots take up limited amounts of nutrients.

Experiments (Allred and Ohlrogge, 1964; Grunes, 1959; Fine, 1955; Haddock et al., 1959; and Robertson et al., 1958) have shown that banding phosphorus and nitrogen-phosphorus mixtures near the seed at planting has improved phosphorus response. Mono-ammonium phosphate, or mixtures of mono-calcium phosphate and ammonium sulfate at rates required for optimum seedling vigor--20 kg nitrogen plus 15 to 30 kg phosphorus (P) per hectare--can be applied with the seed at planting time without seedling damage.

Experiments by Smith et al., (1973) and others (Brage et al., 1960; Mortvedt, 1976) have shown that banding di-ammonium phosphate (DAP), or mixtures of DAP and urea, can result in serious seedling damage from ammonia released during initial soil reactions. These

*Personal communication

problems are more serious for calcareous soils and situations in which fertilizer is applied with equipment that leaves seed and fertilizer in contact. Some deep-furrow, hoe-type seed drills distribute seed and fertilizer over an area 5-7 cm wide. This can be an important factor minimizing ammonia damage from banding DAP or urea near the seed. In contrast, standard double disc drill openers and HZ Zimmerman deep furrow drills cause seed and fertilizer to be in contact.

Ammonia damage to seedlings caused by banding urea and DAP close to the seed at planting is more severe on calcareous soils and when planting into marginal levels of soil moisture (Smith et al., 1979; Mortvedt, 1976). Good soil moisture with rains during seedling germination and development will reduce or eliminate this problem at the moderate rates of nitrogen and phosphorus application required for optimum seeding vigor.

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VII. DRYLAND CROP PRODUCTION

A. The Dryland Characteristic

The dryland concept varies from region to region. It may mean the edge of the desert (Morocco and Tunisia), all of certain similar areas (the Anatolian Plateau of Turkey), or all non-irrigated farm land (Pakistan). The operating definition used here refers to areas that receive 200-500 mm annual rainfall, predominantly during the cool or cold winter season, and experience a two or three month summer drought. Further, in dryland areas non-irrigated crops depend on stored soil moisture and untilled rangeland intermingles with crop land.

Present low crop production levels in developing region drylands is generally believed due solely to insufficient moisture. In reality, crop management--or the lack of it--can be blamed for the prevailing inefficient use of water and low yields. Present crop yields could be improved substantially in both developed and developing nations through more effective use of (the admittedly) limited water supply. Improper tillage, low soil fertility, and weeds all act to reduce yields and, thereby, water use efficiency (W.U.E.). Conversely, crop management that increases production also raises W.U.E. Any cultural practice that conserves moisture which subsequently becomes available to the crop increases yield. During any given crop or fallow season, any moisture lost to weeds, run-off, or evaporation reduces yields. General awareness of the value of any moisture conserved, as a factor in increasing crop yields, seems to be lacking among administrative and technical personnel throughout developing regions.

Effective farming practices developed over the years are geared to efficiently use the limited and variable moisture supplies characteristic of dryland regions. Moisture supply fluctuation not only occurs in annual precipitation, but also in seasonal precipitation. The total moisture supply varies greatly from area to area, somewhat altering soil and crop management practices (Figure 10).

Dryland moisture variations have caused dramatic year-to-year grain production extremes in the past. In many instances, however, even annual and seasonal precipitation variations do not fully explain crop yield instability because of shorter term drought periods.

Figure 10 - ACCUMULATED PRECIPITATION

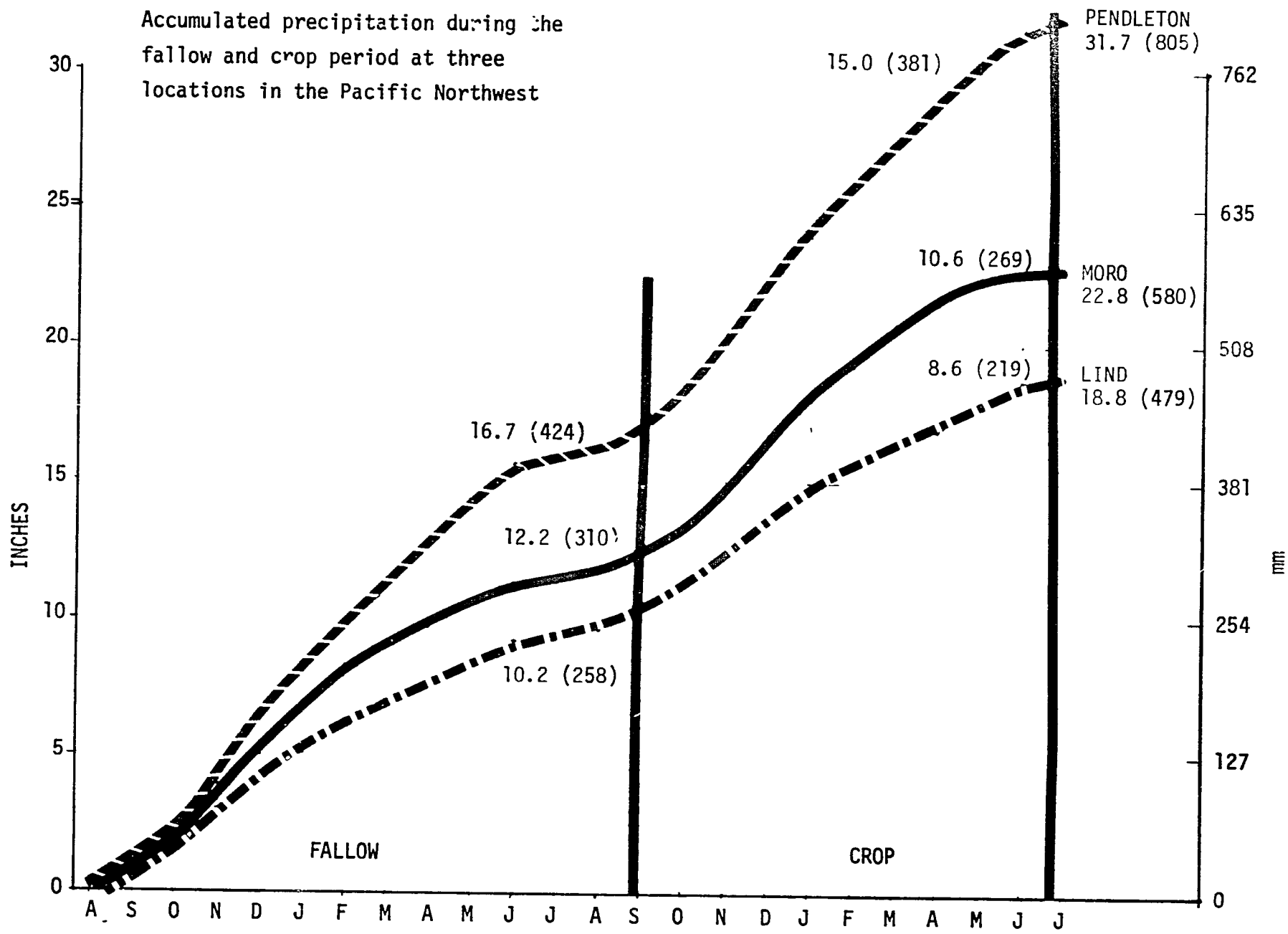


Table 16 - VARIATIONS, PENDLETON, OR / USA

Variations in precipitation and grain yield at Pendleton, Oregon (Columbia Basin Agricultural Research Center)

Precipitation - Seasonal averages and extremes - millimeters

	Annual calendar year		Fallow (14 mo.) Aug.-Sept.		Crop (10 mo.) Oct.-July		Total (24 mo.)	
maximum	1950	555	1949 crop	625	1948 crop	584	1943 crop	1051
46-year avg.		405		428		379		808
minimum	1939	268	1947 crop	298	1973 crop	230	1968 crop	633

Precipitation - Monthly averages and extremes

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
year (max.)	1970	1940	1932	1974	1956	1937	1948	1956	1940	1950	1973	1964
millimeters	133	101	87	92	111	88	44	34	59	107	149	113
46-year ave.	49	38	41	38	34	33	8	8	17	35	49	55
year (min.)	1949	1967	1965	1956	1964	1940	(8 yrs)	(11 yrs)	(5 yrs)	1936	1939	1965
millimeters	9	8	5	3	4	2	0	0	0	3	8	11

Grain yield - Averages and extremes - kg/ha

	Kharkov		Improved varieties	
maximum	1942	3982	1974-Hyslop	6154
46-year average		2852		3592
minimum	1940	1715	1940-Rex M1	1601

Tables 16, 17, and 18 present data on precipitation and crop variations at three sites in the U.S.

To stabilize yields, farmers in certain precipitation zones have traditionally used a fallow-crop management system. Fallow-crop rotation generally is used in the U.S. Pacific Northwest areas receiving less than 350 mm of annual moisture precipitation. Areas receiving 350-450 mm of annual precipitation are transitional to annual cropping, and peas are grown in alternate years with occasional fallow periods to store soil moisture and insure a grain crop. In the Columbia Plateau's more humid zones (greater than 450 mm annual precipitation) annual cropping of cereal grains (wheat, and barley) and peas is practiced, occasionally in rotation with alfalfa or fallow.

Time sequences for tillage and cropping operations under fallow-crop, wheat-pea, and annual grain management systems in the Pacific Northwest appear in Table 19.

B. Water Use Efficiency

In the states composing the Pacific Northwest there are approximately 951,000 ha of fallow land in Washington; 386,000 ha in Oregon; 362,000 ha in Idaho; and 51,000 ha in the Utah panhandle. The fallow land acreage in the region has not varied greatly from year to year since the mid-1930's.

Dryland regions in the mid-western U.S. have a different set of climatic conditions. Generally, a unit of grain requires more annual precipitation to produce in the U.S. Central and Northern Great Plains than in the Pacific Northwest. The data in Table 20 indicate the W.U.E. differences between the two regions.

Considerable progress in soil and crop management, along with variety development, has improved W.U.E. during the past 20 years in the Northwest as shown in Table 21. Grain yield increase at Pendleton, Moro, and Lind was 1.74, 0.92, and 2.56 Kg/mm/ha respectively. No single input was responsible for this increase, but undoubtedly a combination of, and interaction between, improved soil management, better varieties, use of fertilizers, weed control and other agronomic practices contributed.

At the Lind site the increase in W.U.E. for grain yield averaged about 99 percent for the past 22 years when compared to the previous 22 year period. This is the lowest rainfall cereal production region in the U.S. The value of improved varieties does not show as great an influence on grain yields as improved crop management, when considered alone. However, when the influence of improved varieties is added to improved crop management an overall increase of 30 percent in W.U.E. is achieved. Crop management in more arid cereal producing regions appears to play a more dominant role than improved varieties. However, to gain maximum benefit, both elements must be incorporated into a production system.

As precipitation increases, the roles of improved varieties and improved crop management shift in emphasis as shown by data for the

Table 18 - VARIATIONS, LIND, WA / USA

Variations in precipitation and grain yield at Lind, Washington (Dry Land Research Unit)

Precipitation - Seasonal averages and extremes - millimeters

Annual calendar year			Fallow (14 mo.) Aug.-Sept.		Crop (10 mo.) Oct.-Sept.		Total (24 mo.)	
maximum	1948	574	1949 crop	595	1948 crop	537	1948 crop	784
55-year avg.		241		261		220		481
minimum	1930	122	1931 crop	139	1930 crop	121	1930 crop	271

Precipitation - Monthly averages and extremes

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
year (max.)	1970	1940	1938	1944	1948	1923	1948	1969	1927	1947	1973	1973
millimeters	73	109	42	46	149	94	52	34	75	100	85	77
55-year ave.	27	22	19	16	19	23	6	8	13	23	31	33
year (min.)	1949	1967	1965	1949	1966	1949	(14 yrs)	(10 yrs)	1976	1975	1936	1927
millimeters	2	3	1	1	1	1	0	0	0	1	1	4

Grain yield - Averages and extremes - kg/ha

	Kharkov		Improved varieties	
maximum	1942	3350	1967-Moro	3733
55-year average		1594		1762
minimum	1936	276	1936-Rio	269

Table 17 - VARIATIONS, MORO, OR / USA

Variations in precipitation and grain yield at Moro, Oregon (Sherman Experiment Station)

	Precipitation - Seasonal averages and extremes - millimeters					
	Annual calendar year		Fallow (14 mo.) Aug.-Sept.		Crop (10 mo.) Oct.-Sept.		Total (24 mo.)	
maximum	1953	440	1949 crop	483	1951 crop	422	1943 crop	757
65-year avg.		290		311		268		580
minimum	1967	154	1969 crop	190	1968 crop	137	1968 crop	394

Precipitation - Monthly averages and extremes												
Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
year (max.)	1953	1940	1957	1940	1913	1937	1923	1968	1911	1950	1942	1964
millimeters	124	86	85	55	58	67	38	39	102	90	110	155
65-year ave.	43	30	24	19	20	18	5	6	16	24	43	43
year (min.)	1962	1967	1926	1956	1966	(2 yrs)	(23 yrs)	(17 yrs)	(3 yrs)	(2 yrs)	1939	1946
millimeters	6	1	3	0	1	0	0	0	0	0	1	11

Grain yield - Averages and extremes - kg/ha				
	Kharkov		Improved varieties	
maximum	1916	3518	1975-Hyslop	3841
46-year average		1809		2058
minimum	1973	666	1932-Hybrid 128	619

Table 19 - CROPPING SEQUENCE

Cropping operations sequence for three precipitation ranges

Time	Field operations or conditions
Fallow-crop (350 mm precipitation)	
July	Harvest grain
Early September	Fall chisel
September to mid-April	Uncultivated wheat stubble
Mid April	Initial tillage
Mid-April to mid-September	Cultivate fallow
Mid to late September	Plant grain
Late September to late June	Growth of crop
Wheat-peas rotation (350-450 mm precipitation)	
July	Harvest grain
Late July to mid-September	Uncultivated wheat stubble
Mid-September	Plow
Mid-September to early April	Bare
Early April	Plant peas
Late June-early July	Harvest peas (green for canning or freezing)
Early August	Plow
Early August to late September	Bare
Late September	Plant grain
Late September to July	Growth of crop
Annual grain (450 mm precipitation)	
July	Harvest grain
Late July-early August	Plow stubble
Early August-mid-October	Cultivate fallow and prepare seed bed
Mid-October	Plant grain
Mid-October to July	Growth of crop

Table 20 - WATER USE EFFICIENCY

Yield and water-use efficiency of winter wheat grown continuously and after fallow at three locations in the Central Great Plains and in a fallow-crop rotation at three locations in the Pacific Northwest

Location	Average annual precipitation (mm)	Continuous wheat (kg/ha)	Fallow-wheat (kg/ha)	W.U.E.[1/] Continuous wheat (kg/ha/mm)	W.U.E.[1/] Fallow-wheat (kg/ha/mm)
Akron, Colorado 60 yr. average	419	498	1426	1.2	1.72
Colby, Kansas 49 yr. average	470	626	1318	1.3	1.4
North Platte, Nebraska 56 yr. average	495	834	2146	1.7	2.2
Pendleton, Oregon 44 yr. average	403	--[2/]	3518	-	4.4
Moro, Oregon 63 yr. average	289	--[2/]	2004	-	3.5
Lind, Washington 54 yr. average	239	--[2/]	1715	-	3.6

1/ W.U.E. on a harvest to harvest precipitation basis

2/ Data not available

Table 21 - YIELD INCREASES

Grain yield, precipitation and water use efficiency at three locations in the Pacific Northwest

Dates	No. years	Yield (tons/ha)	Total moisture (mm)	Water use efficiency (kg/mm/ha)
Pendleton				
1931-1974	44			
Kharkov		3.03	805	3.76
Improved variety		3.51	805	4.36
1931-1952	22			
Kharkov		2.53	820	3.08
Improved variety		2.84	820	3.46
1953-197	22			
Kharkov		3.15	800	3.93
Improved variety		4.16	800	5.20
Moro				
1912-1974	63	1.81	579	3.12
Improved variety		2.00	579	3.45
1931-1952	22			
Kharkov		1.68	581	2.89
Improved variety		1.82	581	3.13
1953-1974	22			
Kharkov		1.81	569	3.18
Improved variety		2.31	569	4.05
Lind				
1922-1974	54			
Kharkov		1.58	477	3.31
Improved variety		1.71	477	3.58
1931-1952	22			
Kharkov		1.35	518	2.60
Improved variety		1.35	518	2.60
1953-1974	22			
Kharkov		2.01	457	4.39
Improved variety		2.36	457	5.16

Pendleton location (Table 21). The increase in W.U.E. due to improved varieties is almost twice that shown for the Lind location, while the improved crop management effect is less than half that of the lower rainfall zone at Lind. The data suggest that varietal improvement has a greater impact on W.U.E. under more favorable climatic conditions. The interaction between improved varieties and improved crop management indicates about 9 percent increase in W.U.E. at Pendleton compared to 13 percent at Lind.

The overall W.U.E. for grain produced per unit volume of water received was nearly similar for both Pendleton and Lind (5.20 and 5.16 kg/ha-mm respectively). Therefore, both locations are producing at equal W.U.E. levels, but at different yield levels because of large precipitation differences. The benefit of using the best adapted varieties for maximum W.U.E. and increased grain yield can be seen clearly.

Certain climatic and environmental factors, among the many that affect W.U.E. in the production of dryland cereal crops, are beyond control. These include, in addition to a limited moisture supply, distribution and intensity of precipitation, temperature, relative humidity, light intensity, wind velocity, soil type, soil texture, soil depth, and topography of the land. These elements need to be considered and dealt with in production systems, but essentially they are uncontrollable. There are, however, other, controllable practices to aid in efficient use of a limited moisture supply. Those directly related to plant management include: adapted (seed) varieties, stand establishment, plant nutrient-moisture balance, and pest control (weeds, insects, and diseases).

Potential exists for further W.U.E. improvements, particularly through better soil profile moisture storage during the fallow period, and more timely stand establishment during the beginning of the cropping period.

C. Stand Establishment

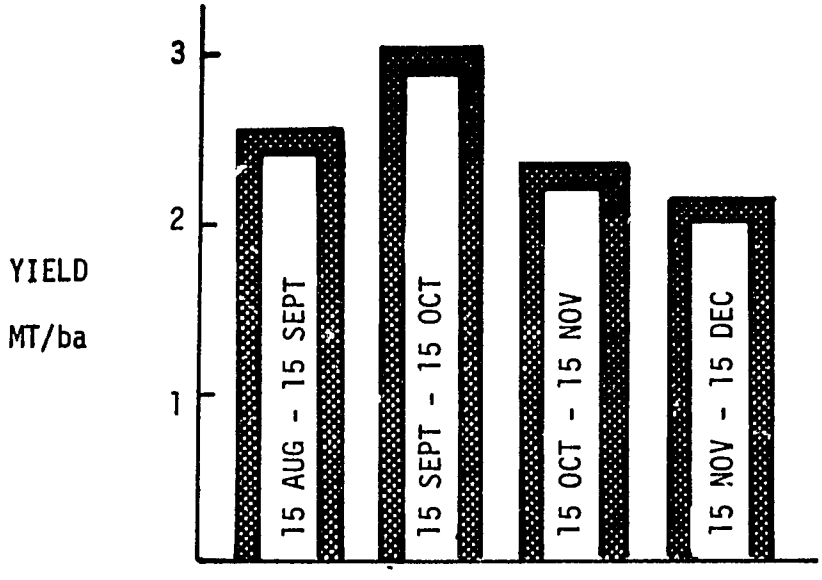
The most important single factor affecting crop yields under dryland conditions, many observers believe, is stand establishment, a term preferable to other commonly used terms, such as seeding date, planting date, or date-of-seeding. Describing the actual time the seeds are placed in the soil does not necessarily insure time of emergence, crown root development, or the appearance of tillers, all of which must occur before a stand can be said to be established.

1. Time of stand establishment

In dryland cereal producing areas with winter precipitation, optimum time of stand establishment may have a considerable effect on water use efficiency (in relation to economic yield) by ensuring that the growth of the crop is adjusted to the available soil moisture. Data in Figure 11, averages of many trials over a period of years, shows the optimum time range for stand established in Eastern Oregon. A number of early trials reviewed indicated no differences in yield due to planting date. Closer inspection of the data revealed that,

Figure 11 - STAND ESTABLISHMENT

Effect of stand establishment timing and grain yield in Eastern Oregon (long term average)



in many cases, grain seeds were placed in dry soil and several days elapsed before a significant amount of precipitation occurred; the date of seeding could have differed by 2-4 weeks, but the time of emergence was the same. Since introduction of deep-furrow drills and the placement of seeds into moist soil (from the previous fallow), data have been more consistent and represented truly different dates of emergence.

Long-term observations (Bolton, 1976, unpublished data) of precipitation in relation to grain yields at three Pacific Northwest locations indicate that whenever significant rainfall occurred during the period of optimum stand establishment (September 15-October 15) grain yields were significantly higher. Apparently adequate soil moisture stimulated emergence and subsequent plant development before low winter temperatures occurred.

As soil moisture conservation practices improved and deep-furrow drills were introduced, seeding into residual moisture became a standard practice. However, seasons still occur when moisture levels for seeding are too far below the soil surface for even the deep-furrow drill. Seeding may be delayed beyond the optimum date while waiting for adequate rainfall, often resulting in reduced yields due to inadequate plant development prior to cold weather.

Pehlivanturk (1976) showed that time from emergence (after adequate moisture was present) to crown root development and tillering

was greatly increased after soil temperatures dropped to a certain range. A critical soil temperature-plant development relationship occurs when the mean soil temperature decreases. This study indicated that when mean soil temperature at seeding depth dropped below 10°C, elapsed time for seedling development of crown roots and/or tillers increased dramatically. Emergence to tillering required 28, 51, and 125 days from October 1, October 15, and November 1, respectively. Mean soil temperature at seeding depth for these planting dates was 16, 9, and 5°C, respectively.

Seeding in dry soil is risky; problems may arise due to either surface crusting following rains, or (sometimes) weed control. However, yield reductions due to late stand establishment are well documented and consistent. The risk in reduced yields from crusting or weeds is not predictable. Even under dry soil conditions timely seeding provides advantages over waiting for adequate moisture to wet the seed zone.

2. Plant population

The optimum number of plants grown per unit area to obtain maximum economic production varies widely for different environments. Under well-watered or irrigated conditions, plant population per unit area above a certain number seems to have little or no effect on subsequent yield (Donald, 1963). When limited moisture conditions exist, plant population and distribution can exhibit substantial influence on water use efficiency and subsequent grain yield (Harper, 1961), provided that the seeding rate is adequate.

For cereal crops planted in rows, adjustments in plant populations and distribution are made either within rows or between rows. Increasing distance between individual plants in the row and reducing the distance between rows to achieve a more uniform distribution over a unit area may defeat its purpose under limited moisture conditions. Brown and Shrader (1959) showed that plants facing minimal competition during the seedling stage tend to produce excessive vegetative growth and deplete soil moisture that could be reserved for grain production at a later date. Larson and Willis (1957) concluded that, to gain maximum benefit from limited moisture, the intra-row population should be great enough to generate adequate seedling stage competition and thereby prevent excessive growth and moisture consumption. The inter-row spaces should be adjusted to fit the moisture supply.

This proposal generally runs contrary to usual practices in many dryland areas worldwide, both developed and developing. Seeding rates (in the row) and row spacings traditionally have been used for two purposes, neither actually related to the best plant population for maximum yield. Greater than optimum seeding rates are employed to provide ground cover for wind and water erosion control. Close row spacings are often preferred to create increased competition for weeds that may grow between the rows. While these concepts may have been partially successful, they undoubtedly contribute to reduced grain yields in many seasons. The work of Arnon (1972) and Arnon and Blum (1964) suggests that improved use of limited moisture supply is possible through greater attention to plant population and distribution in dryland regions.

Several studies conducted in different dryland regions of the world have shown that seeding rates can be reduced and row spacings increased without reducing (and many times increasing) grain yields (Alessi et al., 1971; Bolton, 1973; Guler, 1975; Wilson, 1969). Reasons for not using more carefully adjusted seeding rates and row spacings are many and varied, but none seem to be related to more efficient use of moisture. One study developed results indicating that varieties differ in their response to seeding rates and row spacing in different climatic zones; Guler (1975) found some varieties had differing optimum plant population numbers at each location, while other varieties responded uniformly at a given seeding rate in several locations.

3. Crop varieties

A key to increasing W.U.E., thereby increasing economic yield, stems from planting the most highly adapted variety available. The combination of soil, crop, and pest management practices that conserves moisture for crop growth can only benefit yields if a well adapted crop variety is grown that has adequate yield potential.

Cereal breeding programs generally have similar goals: increasing yield potential and quality, maintaining resistance to pests (insects and diseases), overcoming lodging and shattering, and building in or eliminating other agronomic characteristics. Resistance to, or tolerance of, drouth and heat may be included among breeding goals; but these abilities are much more difficult to capture. Breeders have long recognized that selection for drouth tolerance or heat resistance is extremely difficult because relatively few suitable selection criteria exist presently. Selection in early generation material under dryland conditions is very risky because of extreme variability from season to season (Hurd, 1971). As a consequence, many breeders have resorted to testing larger numbers of later generation lines in dryland areas hoping to isolate types that are better adapted to drouth conditions. This approach has been generally quite successful in the U.S. Pacific Northwest. Many of the varieties with high-yielding potential under adequate moisture conditions have also produced higher yields when moisture is limited. Figure 12 provides an example of the progress made in varietal improvement for dryland conditions.

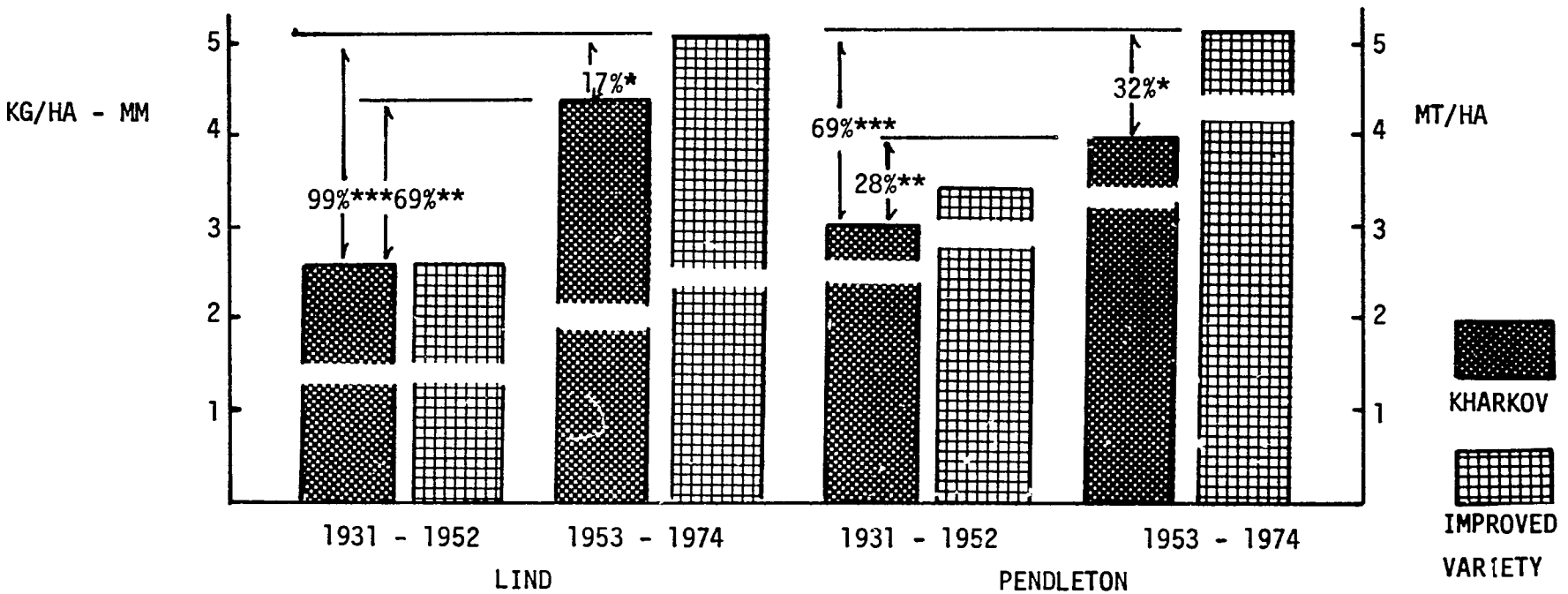
To verify yield potential, crop varieties need to be carefully tested under the particular climatic, soil, and management conditions that will prevail in the field. Consideration should be given to varieties that exhibit ability to yield well under a variety of adverse conditions. Dryland crop production involves numerous variable factors. Varieties intended for the drylands should have an inherent ability to thrive under changing conditions.

D. Tillage and Soil Management Practices

Soil management practices may reflect varying climatic and soil conditions in different regions, but basic principles remain unchanged. Dryland tillage practices are used to: conserve the maximum amount of moisture in the soil profile during the fallow period for use by a succeeding crop; prepare a suitable seedbed so that the

Figure 12 - IMPROVED VARIETIES

Effect of improved varieties and crop management of water use efficiency and grain yield (cross bar) of winter wheat in two locations in the Pacific Northwest



Percent increase due to: *improved varieties; **improved management; ***interaction of improved varieties and management

Kharkov: long-term, standard check variety

Improved Variety: variety most widely grown during the indicated period

crop can be established at the optimum time to efficiently use the limited moisture supply. Rough, cloddy seedbeds are all too prevalent in dryland areas. The condition produces a thin stand of poorly-developed plants which never seem to fully recover during the season.

Tillage operations during fallow usually occur in fall, spring, and summer. Where sufficient precipitation is available for annual cropping, tillage only is used to prepare a suitable seedbed as there is generally no moisture to conserve after an annual grain crop.

1. Fall tillage

In a fallow-grain rotation tillage may occur anytime immediately after harvest until late fall.

Deep chiseling (25-30 cm), or subsoiling (30-41 cm) breaks up hard layers in the soil profile caused by previous tillage operations and aids infiltration of water into the soil profile. This is especially true where frozen soils are common during the winter season. Increases in yield and additional soil profile moisture storage only occur during those seasons when the precipitation is great enough to cause run-off or when there are frozen soils covered with snow that melts while the soils are still frozen. Since these climatic conditions are difficult, if not impossible, to predict, the results from chiseling or subsoiling operations are highly variable. The profitability of any fall tillage in a fallow-crop rotation is questionable at the present time. The practice appears to be location-specific and cannot be recommended over large areas without previous trials in that region.

In some instances, a fall tillage operation helps control grassy weeds during later fallow tillage operations. The question remains, however, whether a less expensive tillage operation might not accomplish the same purpose. At the moment, any fall tillage operation remains the individual farmer's choice without specific recommendations based on research trials.

In grain-pea rotations, fall tillage using a heavy disc or moldboard plow prepares a seedbed for a spring-planted pea crop. Most, or all, of the previous crop's residue is thoroughly mixed or turned under so that spring seeding operations are not hampered by crop trash. These operations usually occur in early fall before winter rains begin.

2. Spring tillage

Initial spring tillage operations utilize three basic types of machine: those that completely invert the tilled soil layer, such as the moldboard plow; those that stir and mix the soil but do not invert the soil layer, such as various types of disc plows; those that cut beneath the soil surface without inverting the soil layer or mixing the surface residues, such as the various types of sweep plow or field cultivators. All three types are widely used, sometimes for specific situations, but often due to an individual farmer's preference.

The inverted layer type tillage (moldboard plow) is generally used where grassy weeds are a problem or heavy surface residues make summer operations difficult. Because it leaves the soil surface bare and without protection, it is not widely used on soils that are subject to heavy wind and water erosion.

The disc and one-way disc plows are intermediate between the mold-board plow and the sweep plow. These implements, if properly used, will leave some residues on or near the surface to reduce wind or water erosion. They may be used when heavy surface residues from the previous crop are present.

The sweep plow is generally used in the stubble-mulch system, whereby the grower aims to leave as much of the previous crop residue on the soil surface as possible. It approaches the ideal tillage system for soil conservation and erosion control. However, heavy surface residues and presence of large populations of grassy weeds make the stubble-mulch system impractical in many instances. If adequate chemical control of grassy weeds were possible, this system would be practiced more extensively.

Early initial spring tillage helps conserve soil moisture previously stored in the soil profile. Many studies have shown that early spring tillage is preferable to late spring tillage because it destroys weeds and volunteer grain that would use soil moisture. Data for most dryland areas with a winter rainfall pattern indicate that precipitation received after the first week in April adds little, if any, additional moisture to the soil profile. Vegetative growth of volunteer grain and weeds, if present, will remove more moisture than will be stored from precipitation.

All three initial spring tillage methods have been successfully used in fallow moisture conservation management programs. Each method has its own benefits and disadvantages in a given area, extensive field research trials have generally shown which system is particularly adapted. Often each season's climatic conditions will dictate the system to be used. U.S. dryland farmers commonly have an array of tillage equipment for initial spring tillage and use only the machines that suit the prevailing conditions.

In grain-pea rotation areas, the initial spring operation involves preparing a seedbed for planting peas. A variety of implements may be needed, but generally discing and harrowing are used to prepare a relatively smooth seedbed. Operations have to be conducted promptly since optimum pea planting time is relatively short. Most peas are grown under contract to be harvested green for canning or freezing. Some may be allowed to mature for harvest as dry peas.

3. Summer tillage

Tillage operations conducted during late spring and throughout the summer have three primary purposes: control weeds; maintain a soil-residue mulch that will conserve moisture stored in the soil profile; and, prepare an adequate seedbed for planting the crop, that is, hold residual moisture close enough to the soil surface so that seeding operations can be conducted at the optimum time as nearly as possible.

In recent years the most widely used implement for these purposes has been the rodweeder. This implement, when properly used in previously well-prepared fallow, fulfills the purposes of summer tillage in an economical manner. The market offers numerous variations of the rodweeder to fit different soil conditions throughout dryland areas. Some combine sweep cultivation with rodweeder operations for use where the particular condition requires it. Heavier soils usually require more drastic tillage action to maintain proper soil particle size and mulch depth to conserve fallow moisture. A sweep or field cultivator teamed with one of several types of harrows may be used early in the summer tillage operations followed by the rodweeder in late summer or early fall.

E. Seeding

Dryland cereals planted in fall are subject to a variety of winter climatic conditions that ultimately determine yield. A poorly developed plant facing a cold winter uses more (limited) moisture supply for recovering during spring than a healthy, well-developed plant. Good fallow practices include both conservation of total moisture in the soil profile, as well as seed zone moisture. The latter is critical for crop germination and emergence.

Seeding into residual moisture can be accomplished best by a properly adjusted deep-furrow grain drill. The predetermined number of seed per meter of row must be placed under 2.5-5 cm of moist, firmed soil. Seeding equipment should preserve as much residue as possible and securely anchor the residue in the ridges, leaving a rough, cloddy surface.

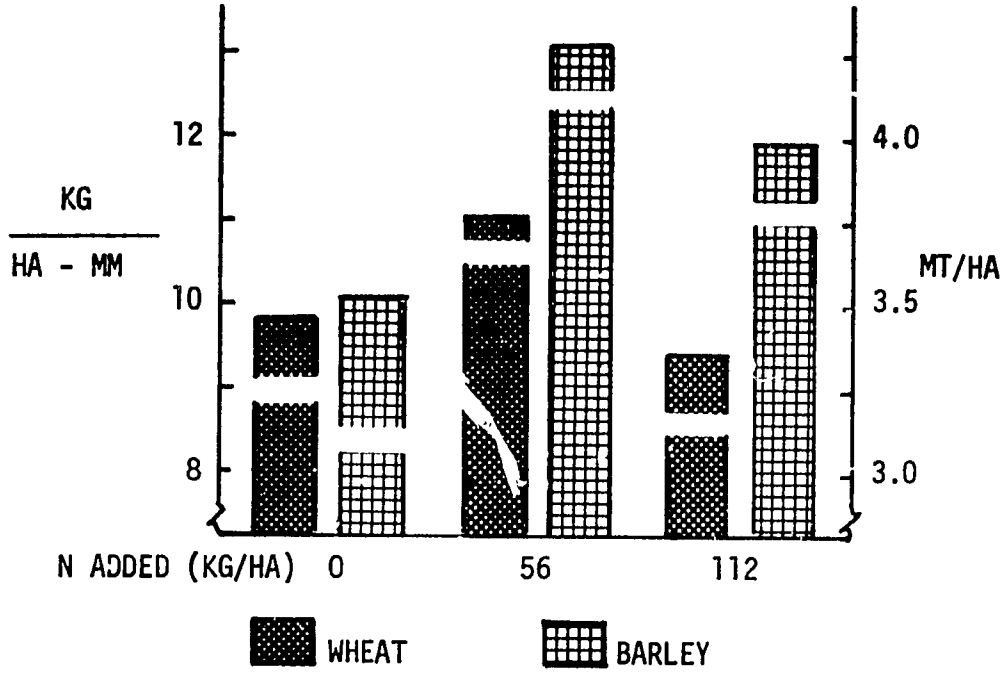
When subnormal or poorly distributed precipitation occurs, even the most progressive farmer may be unable to maintain soil profile moisture close enough to the surface to seed at the optimum date. Under these circumstances seed should be placed at a shallow depth so that rainfall can trigger germination and emergence. Data clearly demonstrate that as few as five to seven days earlier emergence in fall can produce a significant positive effect in crop yield.

F. Plant Nutrition

In areas of limited precipitation, a balanced nutrient supply enables a crop--at all stages of growth--to use the available moisture supply with greater efficiency (Arnon, 1975, 1972; Olson, et al., 1964; Viets, 1962, 1971, 1972). A nutrient deficient plant, even when not growing, or growing slowly, uses water at about the same rate as a nutritionally balanced plant, yet produces considerably less yield (Asana, 1962; Aspinall, et al., 1964; Brown, 1970; Leggett, 1959). Recent information by Aktan (1976) confirmed these findings and indicated that differing soil moisture levels at seeding require different amounts of nitrogen for a balanced moisture-nitrogen supply and maximum W.U.E. An example from this study (Figure 13) reveals that W.U.E. can be decreased markedly by either a nitrogen deficiency or excess.

Figure 13 - NITROGEN AND W.U.E.

Effect of nitrogen fertilizer on W.U.E. and grain yield (cross bar) of winter wheat and barley at Moro, Oregon, 1975.



Highly variable moisture conditions typical of dryland regions tie fertilizer requirements to the prevailing moisture supply when efficient use of water is the goal. Moreover, various soil management methods--bare fallow, stubble mulch, minimum tillage, or no-till (chemical fallow) systems--may require different levels of nitrogen to achieve the proper moisture-fertilizer balance (Brown, et al, 1960; Greb, et al, 1967; Koehler, et al, 1967; Oveson and Appleby, 1971). The quantity of plant residues left on the soil surface or mixed in the upper few centimeters can significantly influence the amount of nitrogen available to the crop plant (Leggett, et al, 1974; Smika, et al, 1969; Smika, 1970). Generally, the more surface residue present, the more nitrogen required to balance fertilizer needs with the moisture supply.

Olson, et al, (1964) found that nitrogenous fertilizers stimulated excessive initial vegetative growth if the total nitrogen required for the growth was applied in a readily available form at seeding. Applying fertilizers sparingly at seeding led to desired seedling plant development devoid of excessive vegetative growth. Current information suggests that increased attention be given to "starter" type fertilizers that are nutritionally balanced for supporting stand establishment of winter cereal crops. Additional nitrogen could be added later at an appropriate growth stage.

In the Pacific Northwest, where most nitrogen fertilizer is injected into the soil (20-25 cm deep) in a gaseous or liquid form

several months prior to seeding, the zone of nitrogen accumulation appears to be well below the seedling root zone. This practice causes an apparent nitrogen deficiency in the early growth stage which gradually disappears as plant roots reach the accumulation zone. The nitrogen deficiency period may last a few weeks or several months depending on the soil temperature. Consequently plant development is retarded prior to cold weather and stimulated during spring warm periods. The result can be--and often is--excessive moisture use that could have been avoided with proper nutritional balance during stand establishment.

Even though nitrogenous fertilizers receive major emphasis, other fertilizer elements play an important role in increasing dryland W.U.E. Phosphorus, potassium, sulphur, and the other minor elements required for plant growth and development must be available in the proper amounts or yields will suffer (Brown, et al, 1960; Gardner, 1964). These other fertilizer elements, while not as dependent on the moisture supply as nitrogen, are needed to avoid a profound negative effect on the W.U.E.

Knowledge of the soil's nutrient status is essential for producing crops under dryland conditions. Maximum efficient use of available water supply controls successful dryland crop production, and this can be achieved only when nutrient deficiencies are corrected. However, fertilizer usage, even though in proper amounts and balances, without attention to other cultural practices such as seedbed preparation or weed control, often does not increase yields.

G. Crop Protection

Factors that slow or block crop growth and development warrant full attention and correction, where possible. Control of insects and diseases under virtually any conditions enhances crop yields. Control is particularly essential for dryland farming because limited moisture supplies may preclude recovery of a pest-injured crop. Under high rainfall or irrigated conditions, a damaged or weakened crop may have a chance of recovery. With limited moisture conditions yields are irretrievably reduced.

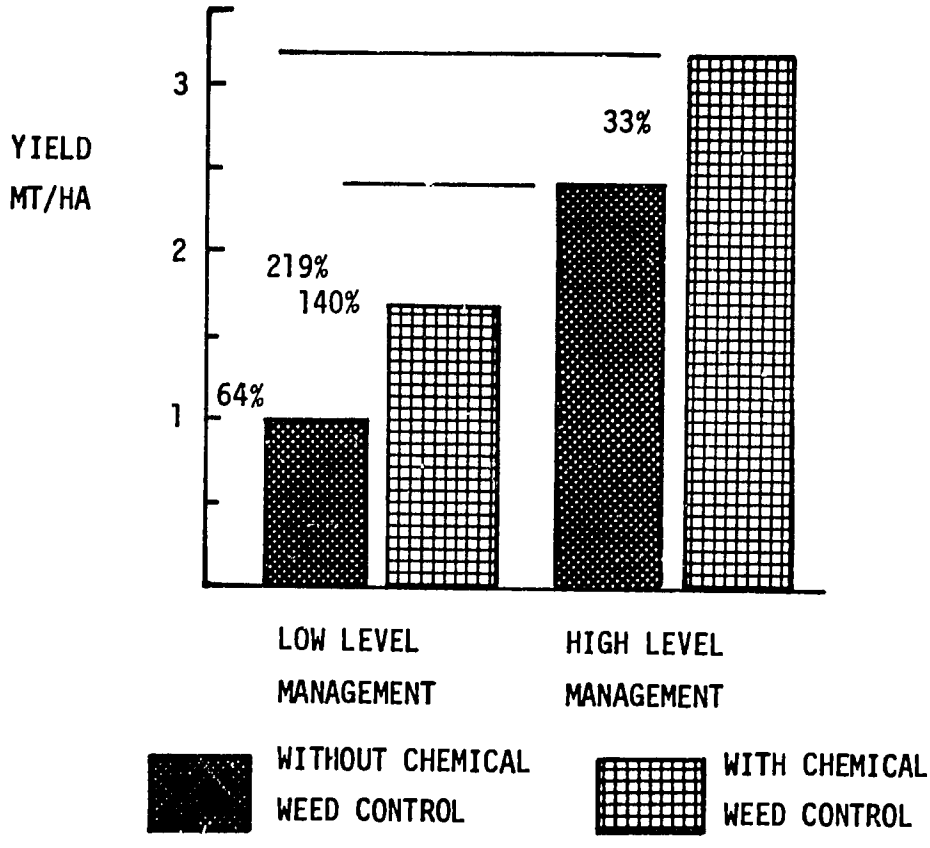
Although control of weeds is not directly related to management factors affecting crop plant water use efficiency such as variety, stand establishment and moisture-fertilizer balance, it is no less important. In fact, application of other improved cultural practices (high yielding varieties, fertilizers, improved tillage methods or better seedbed preparation) without adequate weed control will generally lead to disappointing yield results. Timely, effective weed control is the first step toward reducing water loss and thereby improving yields in the drylands. Each increment of water used by weeds reduces moisture available to a crop. Weeds need to be controlled in the early stages of crop growth. Numerous studies document early competition between weeds and crops--for nutrients and light as well as moisture--as the most damaging.

Generally speaking, the more limited the moisture supply, the more critical adequate weed control becomes. Hepworth et al., (1975) showed that even with poor soil and crop management, timely

chemical weed control delivered sizable yield increases. Weed control coupled with improved crop management practices increased grain yield 33 percent (Figure 14).

Figure 14 - WEED CONTROL

Effect of weed control and management on yield of winter wheat in Turkey, 1974 - 1975.



Chemical weed control plus traditional management increased grain yields about 64 percent, but at a yield of only 1.54 mt/ha. A certain amount of cultural weed control is achieved under improved soil and crop management. Hence, addition of chemical control during the crop growth period caused a less impressive yield increase. However, total yield increases due to weed control under improved management averaged 0.8 mt/ha compared to about 0.5 mt/ha under poor management.

Heavy weed infestations in both cropped and fallow lands are common throughout the LDC's. Even when weed control is practiced, often it is not correctly timed and a substantial yield loss still occurs.

Many available herbicides control most broadleaf weeds. Additional control measures--chemical, cultural, and combinations--may be required to control several species of weedy grasses. Extensive

research in process will hopefully help solve the problem of weedy grasses that plague cereal crops worldwide.

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VIII. DRYLAND FARMING EQUIPMENT

The success of dryland farming systems depends on making maximum use of a limited soil moisture supply. These systems involve conserving as much moisture as possible from rainfall and snow, storing it in the soil, selecting a suitable crop, and using cultural practices that provide maximum utilization of the available stored moisture for crop production (Burrows, 1970).

The size of dryland farms vary from less than a hectare to many thousands of hectares. For the most part, land tends to be steep and rocky with poor, shallow soils. Current farming practices range from primitive hand methods developed in ancient times to completely mechanized systems involving complex machines and sophisticated management techniques. Local climatic, soil, social, and economic conditions influence which production systems are used in a particular region. As yet, no single crop production system has been devised that can be applied advantageously to all dryland regions of the world. However, adoption of some improved practices could substantially increase production in many areas.

Dryland farming in developed countries has embraced a high degree of mechanization. Mechanization may be defined as: scientific application of mechanical aids to increase production and preservation of food and fiber crops with decreased drudgery and greater efficiency compared to primitive methods. Mechanization can increase crop yields through: increased control of soil and moisture losses; improved seedbed preparation; more timely seeding and more accurate seed placement; more effective weed, insect, and disease control; and better harvesting, processing, and storage practices.

Timeliness of farming operations is critical in maximizing yields and efficiently using available crop land (Esmay and Hall, 1973). Mechanization, perhaps more than any other benefit, has given dryland farmers greater control over the timing of their operations.

Of course, mechanization requires additional capital investment in equipment, mastery of increased knowledge and different skills by the farmer, access to supporting activities and services, and use of improved management practices. To be successful, mechanization must involve more than just "tractorization." The equipment and methods selected need to be appropriate for the area where they are to be

used. The maximum benefit of mechanization hinges on proper training and education of the involved workers and management personnel.

A. Tilling

Tillage is a fundamental crop production practice. Its primary objective often is limited to creating a seedbed with favorable soil conditions for seed germination and subsequent plant growth. Moisture conservation becomes an equally important tillage objective for dryland farming where limited moisture affects crop production.

Approved tillage practices contribute to increased crop yields, higher net income per unit land area, and lower unit cost of crop produced. Poor tillage practices, on the other hand, can be very detrimental. This holds particularly true for dryland farming where a high risk exists even under the best of conditions. Incorrect tillage can drastically reduce stored soil moisture. Exposing moist soil to air and sunlight accelerates evaporation rates. Improper tillage can also contribute to increased wind and water erosion by destroying soil structure and removing vegetative cover from the soil surface (Jensen and Weiser, 1969).

Generally, dryland crop production will be enhanced if the tillage practices used involve: controlling weeds that use water; leaving crop residues on the land surface to promote moisture retention and erosion control; maintaining a high infiltration rate potential; maintaining a high percentage of surface clods for erosion control; avoiding tillage practices that loosen or turn up moist soil and expose it to rapid drying; and, developing a firm, mellow seedbed (Fenster, 1973).

Tillage implements can be classified several ways. They can be listed in categories of power sources required for their operation: hand-operated, animal-drawn, and tractor-drawn. They also may be classified according to the nature of the soil manipulating operations performed: breaking and stirring without inversion of the tilled soil layer, breaking and cutting, turning or inverting the soil layer, and cutting and turning (Hopfen, 1969). A third system groups implements according to whether they are used for primary or secondary tillage operations. Primary tillage is usually the deepest and most aggressive of tillage operations performed. Secondary tillage involves weed control and seedbed refinement operations which are performed after primary tillage. All three classification systems will be used to describe the wide variety of tillage tools used in dryland farming throughout the world.

1. Hand tools and animal traction

Spading and digging hoes are still used for primary tillage operations in parts of Africa, Europe, the Middle East, the Far East, and in the Andes region of Latin America. Because man is a limited source of power, hand tillage methods are slow and arduous. The physical condition of the individual, the nature of the task, the length of the work period, and the effectiveness of the tools used help determine the amount of work that can be accomplished. Typical work rates might vary between applying a 50 N force with a velocity

of 1.1 m/s to a hand-operated lever, to a 625 N force at 0.15 m/s when operating a water ladder. These translate as power outputs of approximately 0.3 W for a short period to 0.08 W for a sustained period (Hopfen and Biesalski, 1953; Van Cott and Kinkade, 1972). Consequently, the performance rate for hand tillage is quite slow. In the Anatolia region of Turkey, for example, workers can spade approximately 0.4 ha/day/man (Karpat, 1960). Only small areas of land can be tilled by hand due to the need for timely tillage.

Animal power for draft purposes began several thousand years B.C. and increased man's productivity in terms of both the amount and quality of work accomplished per unit time. Many animal-drawn tillage implements doubtlessly evolved as adaptations of hand tools. One of these is the ard, generally regarded as forerunner of the modern plow.

Ards are usually made of wood; some may have metal points or shares. Ard forms are peculiar to different geographical areas. Beam ards incorporate a curved tilling beam, the main structural member of the implement, to which the handle and soil engaging element are attached. Beam ards are used in Ethiopia, Northern Tunisia, Chile, Central and Southwestern Iraq, Syria, Lebanon, Jordan, Iran, parts of Turkey, and Eastern India.

Body ards are probably the most widespread style being found in Morocco, Algeria, Afghanistan, India, Syria, Iraq, the Balkan Peninsula countries, the Far East, and in many Latin American countries. They are characterized by a main body member; one end is the pointed soil engaging unit while the other inclines upward and tapers off to form the handle. The pulling beam attaches to the body. The body ard, sturdiest and heaviest of the ard groups, is suitable for deeper tillage.

More recently, an ard has been developed with a horizontal sole body sliding on the ground. The handle and pulling beam are fitted to the sole body. These are light weight, shallow tillage implements used extensively in dry zones. Sole ards are found in many countries including Tunisia, Libya, Algeria, Morocco, the Arab Republic of Egypt, the Eastern Balkans, Turkey, Iran, Iraq, Afghanistan, and Pakistan (Hopfen, 1969).

While construction details may vary, the ard's basic soil manipulating function is the same. They are primarily breaking and digging or breaking and cutting implements. Very little soil inversion takes place; the soil surface is left with a ridged configuration and most vegetation present remains on the tilled surface (Hopfen, 1969). Ards are not effective implements for weed control and moisture conservation. In Eastern Anatolia, for example, tillage operations occur in late spring or early summer, often after the weeds have wasted extensive stored soil moisture. Many weeds survive initial tillage and continue to grow and use moisture. A subsequent tillage operation may be required in late summer to allow the sun to "burn and purify the soil." As a result, soil moisture becomes depleted down to the subsoil (Ross, 1967).

Other animal-drawn primary tillage tools commonly used in

dryland regions include the moldboard plow, the disk* plow, and, to a lesser extent, the chisel plow. While the operating principles of these implements are similar to their tractor-drawn counterparts, the size and construction are not. Animal-drawn tools are usually lighter weight units designed for animal-paced operating speeds that are slower than feasible with most tractors. Indiscriminately pulling animal-drawn implements behind a tractor can result in damage to the equipment, poor operating characteristics, and undesirable results.

2. Primary tillage

Tractors and modern equipment have been responsible for substantial changes in dry region tillage practices. The tractor's increased pulling capacity, coupled with heavier equipment, permitted cultivation of dry, hard soils that defied hand and animal-pulled tillage methods.

Implements used with tractors are available as mounted or integral, semi-mounted or semi-integral, and trailed or pull-type units. The designation defines the implement-tractor relationship when the implement is in the transport position. Tractors carry the entire weight of a mounted or integral machine. The implement may have one or more wheels and still fall in the mounted category. A mounted moldboard plow, for example, may have a gauge wheel which is in contact with the ground during plowing, but does not support any implement weight when the plow is lifted out of the ground. Semi-mounted implements split their weight between the tractor drawbar and their own wheels. Trailed implements have their own running gear that supports the total implement weight.

The moldboard plow is the world's most universally used tillage tool. Its soil engaging unit--or "bottom"--is essentially a three-sided wedge. Forward movement causes the wedge to slice and invert a strip of soil. The amount of inversion and degree of soil pulverization achieved depend on a number of factors, some related to the soil and others related to the plow itself. The former include soil type and moisture content, previous cropping and tillage, as well as type and amount of vegetation. Plow related factors are moldboard curvature, travel speed, attachments used with the plow, plow adjustment, and the general mechanical condition of the plow.

Seedbed preparation and weed control stand as two important moldboard plow uses. In fact, some moldboard plowing may have a positive effect on crop yield. During adoptive tillage research in Turkey, moldboard plowed plots out-produced plots in which other primary tillage methods were used (Bolton, et al., 1971a). Inverting the furrow slice effectively controls many weeds. Infrequent moldboard plowing is recommended in the Pacific Northwest for controlling cheatgrass (Bromus tectorum).

The world market offers mounted, semi-mounted, or trailed moldboard plows with from one to twelve bottoms, depending on style. Standard bottom sizes range from 254 mm to 560 mm wide. Attachments commonly associated with moldboard are jointers, rolling coulters,

*Disk (also spelled disc) has been adopted in this study.

trash boards, and moldboard extensions. Jointers and trash boards increase crop residue coverage or burial. Rolling coulters reduce draft by helping to cut the furrow slice free in the vertical plane and in cutting through crop residues. Notched and ripple coulters are used in heavy residue conditions. The moldboard extension provides additional control of the furrow slice during the inversion process. A spike-tooth harrow or other soil pulverizing device may be pulled behind the plow to break up clods and begin formation of the soil mulch that is instrumental in reducing evaporation losses.

In spite of wide usage, the moldboard plow has disadvantages for dryland farming. The plow's inverting action exposes moist soil and accelerates evaporation losses. It also buries nearly all crop residue which severely reduces wind and water erosion protection. (A conventional moldboard plow can be converted into a stubble mulch implement by replacing the moldboards with plates 100 mm wide; the soil surface after plowing has a rough and cloddy condition with most of the crop residue left on the ground surface or lightly mixed with the surface soil (Horning and Oveson, 1962). The moldboard plow is a high draft implement with equivalent power requirements. Approximately 150 t/ha of soil are moved and turned for every 10-mm of plowing depth. Plowing deeper than necessary for seedbed preparation, weed control, or compacted sole breakup materially adds to tillage costs (Arnon, 1972a).

Another tillage implement widely used in the world's dryland farming regions is the disk plow. It may be used for either primary or secondary tillage operations depending upon its size and design. Minimal crop residue burial occurs due to soil pulverization by the cutting and lifting action of rolling, concave blades rather than complete soil inversion. Soil penetration by the disk blades depends on: implement weight, disk blade diameter, angle between the disk blade and both the soil surface and the direction of travel, and operating speed.

Disk plows have a distinct advantage over the moldboard plow under several field conditions. Disk plows can operate in soils too dry and hard for the moldboard plow to penetrate, in highly abrasive soils that cause excessive wear to moldboard plow bottoms, in stickly soils that do not scour well, and in soils containing rocks and other obstructions that could cause mechanical damage to a moldboard plow bottom. Disk plow power requirements essentially equal those of moldboard plows operating at the same depth.

Machines are classified as a standard disk plow or a vertical disk plow depending on blade mounting. Each standard disk plow blade is individually supported by a structural member called a standard. A vertical disk plow carries all its blades on a common arbor or gang bolt. Its individual blades turn in a plane that is always vertical to the ground. Disk plows are manufactured in mounted, semi-mounted, and trailed models.

Standard disk plows are more versatile because the angle their disk blades make with both soil surface and direction of travel can be adjusted to accommodate field conditions. These primary tillage machines are noted for their heavy construction. Implement weights range from 180 to 540 kg per disk blade (Kepner, et al., 1978).

Additional weight can be added to the plow frame to achieve desired depth of penetration in hard soils.

Standard disk plows have one to six blades, generally ranging from 610 mm to 710 mm in diameter. At least one manufacturer produces a machine with 1.27 m diameter blades. Large disk blades, wide standard spacing, and high under-beam clearance produce an implement well suited for use in heavy stubble. Plowing depth helps determine crop residue amounts remaining on the soil surface. In tests conducted in the U.S. at Pendleton, Oregon, in a field with 5.6 t/ha of straw on the ground, 50 percent remained on the soil surface after plowing (Horning and Oveson, 1962).

Generally, vertical disk plows have lighter construction, smaller disks, and closer disk spacings than standard disk plows. They are used mostly for relatively shallow tillage. Typical implement weights range from 45 to 90 kg per disk blade. Disk diameters are usually 610 to 710 mm with 200 to 250 mm spacing (Buckingham, 1976; Kepner, et al., 1978; Stone and Gulvin, 1977). Although small mounted disk plows are available, the majority are trailed type units having 2 to 6 m cut widths. The width of cut can be adjusted to match field conditions and available tractor power. This can be accomplished by adjusting the hitch linkage to change the angle between the disk blades and the direction of travel. Multiple hitches allow hooking two units together for use behind larger tractors.

Vertical disk plows effectively incorporate excessive crop residues into the soil. As with standard disk plows, the deeper the tillage, the greater the reduction in the crop residue remaining on the surface (Horning and Oveson, 1962). Large units can till bigger areas in relatively short periods of time. For example, a typical vertical disk plow used in the U.S. Great Plains region may have thirty 500 mm diameter disk blades spaced 200 mm apart and, when pulled by a 110 kW tractor at 8 km/h, can cover approximately 4 ha/h (Arnon, 1972b). The vertical disk plow is also referred to as wheatland plow, disk tiller, harrow plow, one-way disk, or cylinder plow.

Chisel plows and sweep plows fit within a group of subsurface tillage implements that find favor in U.S., Turkish, and other dryland regions. These machines loosen and pulverize the soil without inverting it. Consequently, crop residues remain predominantly on the soil surface providing protection against wind and water erosion (Oschwald, 1973; Burrows, 1970; Bolton, et al., 1971a); Horning and Oveson, 1962; USAID/OSU, 1975). Chisel plows exhibit sturdy construction. Manufacturers offer mounted or trailed units in 2.5 to 12.5 m widths. Heavy flexible or spring-cushioned shanks support the soil engaging units which may be straight or twisted shovels, spikes, or sweeps, depending on tillage objectives. A chisel plow should have high under-frame clearance, as well as shanks staggered in two or three ranks if operated in heavy residue conditions.

Chisel plow draft falls substantially below that of a moldboard plow having an equal width of cut because the chisels displace approximately half as much soil of moldboards. Consequently, a tractor can till more land with a chisel plow than with a mold-

board plow in the same field (Buckingham, 1976).

Chiseling generally implies breaking through and shattering compacted or otherwise impervious layers to improve soil infiltration characteristics. Best results from chiseling occur when the soil is dry (Kepner et. al., 1978). Substantial benefits have been realized in areas where the soil freezes in the winter. The rough surface left by the chisel plow traps snow. Water from melting snow enters the soil through the chisel gaps. One U.S. study found that chisel plowed land stored 30 percent more moisture than unchiseled land (Leggitt et al, 1974). Chiseling deeper than 400 mm is usually referred to as subsoiling (Oschwald, 1973).

Subsurface tillage may be performed at various depths depending upon the desired result. An initial tillage operation might involve using 38-75 mm wide shovels operating 150-250 mm deep. Twisted shovels--having a slight side-throw action--are recommended for use in heavy residue conditions, whereas straight shovels are used under ordinary conditions (Pumphrey, 1975; Horning and Oveson, 1962).

The sweep plow, a subsurface tillage tool, mounts one or more V-shaped blades on standards attached to a frame. Some units, however, employ straight blades. Except in the space immediately adjacent to the standard, there is relatively little disturbance of the surface soil except some breakage (Buckingham, 1976; Pumphrey, 1975; Horning and Oveson, 1963). Sweep plows, like chisel plows, are ruggedly built. They also require high under-frame clearance to operate in heavy residue conditions.

Units with from one to five V-shaped blades, each ranging in width from 1.5 to 2.4 m, have been operated successfully in unmulched stubble and crop residue up to 4.9 t/ha, and in up to 6.74 t/ha of mulched stubble (Horning and Oveson, 1962). Proper adjustment of a sweep plow is important. Blades need to be level to avoid excessive implement draft, uneven blade wear, nonuniform tillage depth, and varying amounts of soil displacement (Horning and Oveson, 1962).

Numerous locally developed machines supplement commercially available tillage equipment. One such indigenous machine, the "Arab Plow," is used extensively in Lebanon and Syria. It is a tractor-mounted, multiple purpose version of the beam ard. It is employed for both primary and secondary tillage, covering broadcast seeds, incorporating broadcast fertilizers, cultivating, weed control, and digging potatoes (Henderson and Sorush, 1972; Henderson and Siddiqui, 1969).

3. Secondary tillage

Seedbed preparation and refinement, covering broadcast seeds, weed control on fallowed land, crop residue management, breaking up rain-formed crusts, and establishment and refinement of soil mulches for moisture conservation are all secondary tillage procedures. A wide variety of manual, animal-drawn, and tractor-drawn implements are used for these purposes. Hand-operated tools include hoes, rakes, and hand cultivators for preparing seedbeds and controlling weeds. Animal-drawn implements in use include wooden brush (limbs or small trees), peg or spiked-tooth harrows, spring-tooth harrows, clod mashers and rollers, and disc harrows (Hopfen, 1969). Limited

man and animal power outputs impose limitations on secondary tillage operations similar to primary tillage.

The field cultivator appears similar to a slimmed down, lighter weight chisel plow. Field cultivators are secondary tillage implements primarily used for weed control and seedbed preparation (Buckingham, 1976; Kepner, Bainer and Barger, 1978). They are also used frequently to reduce straw length to facilitate seeding operations, to create a cloddy soil surface for wind erosion control, and to renew a surface mulch that has been puddled by a heavy rain (Leggett et al, 1974). Shovels, spikes, and sweeps are also used on field cultivators. Field cultivators may be either mounted or trailed. Typical widths for mounted field cultivators range from 2.7 to 7.3 m. Trailed units up to 18.3 m wide are offered.

After an initial tillage, the shovels of a chisel plow are normally replaced by sweeps for seedbed preparation and weed control. Sweeps 300 to 500 mm wide, sometimes referred to as "duckfeet," are commonly used. Tillage using sweeps occurs at depths of 75 to 125 mm performed in either a perpendicular or diagonal direction to the first operation. Changing directions insures uniform depth of tillage and reduces ridging effects. Uniformly tilled soil helps conserve moisture and facilitate rod weeding later in the season (Horning and Oveson, 1962).

Disk harrows, in some instances used for primary tillage, generally operate as secondary tillage tools for seedbed preparation and weed control. Under some dryland conditions, disk harrows have been found less satisfactory than machines employing sweeps. Disked soil may be too finely pulverized and not sufficiently packed to provide an ideal seedbed. The desired seedbed firmness can be achieved, however, by pulling a spike-tooth harrow behind a disk harrow. Disk harrow-tilled soil also may experience wind and water erosion as crop residues are more extensively incorporated into the soil than when sweeps are used (Pumphrey, 1975). Disk harrows have been used in adoptive tillage trials in Turkey and Jordan (Goetze, 1970; Bolton, 1973; Bolton et al., 1971a). Both mounted and pull-type disk harrows are available.

A disk harrow consists of two or more gangs of concave or cone-shaped disks or blades. Several disks are mounted on a common axle or gang bolt. Disk harrow blades usually are smaller diameter and spaced closer together than those of a disk plow. Blade diameters range from 406 to 660 mm and blade spacings from 178 to 254 mm. Disk blade edges may be either smooth or notched, the latter configuration being most effective for cutting through heavy crop residues. Gangs are designated as right hand or left hand depending on the direction that they move soil. Disk harrows can be either single-acting or double-acting implements. Single-acting models have two gangs of disks, placed end to end, which throw soil in opposite directions. Animal-drawn disk harrows and small tractor-drawn units tend to be this type. Double-acting versions have the gangs arranged in a manner that tills the soil twice with each pass and leaves it more nearly level (Pumphrey, 1975; Kepner et al, 1978).

The gang arrangement of double-acting disk harrows classifies them as either tandem or offset. A tandem disk harrow has four gangs; the two front gangs move soil outward from the center of the

tilled strip, the back two gangs throw the soil back. Tandem disk harrows are referred to frequently as double disks and plain disks.

Offset disk harrows display heavier construction than tandem units, thus making them more suitable for deep primary tillage operation. An offset has a front or right hand gang and a rear gang or left hand gang. Larger diameter blades and wider blade spacing characterize offset disk harrows. Offset disk harrows get their name from the fact that by changing gang angles, with respect to the direction of travel, the implement's center of draft shifts or "offsets" from the center of the tilled strip (Kepner et al., 1978). These machines are also referred to as orchard disks and cover crop disks.

Disk harrow weight, blade size, gang angle with respect to the direction of travel, and operating speed influence tillage depth achieved. The gang angle may be fixed or adjustable. Some units are equipped with wheels to control tillage depth and facilitate out of field travel. Effective cutting widths range from 1.8 to 7.3 m.

Spike-tooth harrows, also known as peg tooth harrows, drag harrows, section harrows, and smoothing harrows, principally smooth and level the soil after some other tillage operation, refining seedbeds by breaking clods, compacting the soil in a loose seedbed prior to planting, and covering broadcast seeds. Pulling a spike tooth harrow behind a plow is recommended practice in Turkey and Jordan (Goetze, 1970; Pumphrey, 1975). The spike-tooth harrow has been used in conjunction with other implements, such as chisel plow, sweep plow, disk harrow, and rod weeder in adoptive tillage trials in Turkey and Jordan (Bolton, 1973; Bolton et al., 1971a; Zinn, 1975; Bolton et al., 1971b).

The spike-tooth harrow has rigid teeth resembling long spikes. High carbon steel teeth having a 16 X 22 mm diamond-shaped cross section are commonly used. Tooth angle may be fixed or adjustable depending upon a particular unit. Spike-tooth harrows are relatively light draft implements.

Tine-tooth harrows were developed relatively recently. They are similar in construction to a spike-tooth harrow except for having flexible spring steel tines, approximately 8 mm in diameter, instead of rigid teeth. Tine-tooth harrows effectively break up clods and smooth seedbeds. Some growers consider tine-tooth harrows to be more effective in distributing crop residues than spike-tooth units. Tine-tooth harrows may be pulled behind other implements--moldboard plow, chisel plow, sweep plow, or disk harrow--or used independently. These machines, also referred to as mulchers, weeder-mulchers, and clod breakers, are available in a wide range of sizes.

Rotary hoes have a series of curved-tine wheels or spiders mounted on a common axle. The wheels rotate in a vertical plane parallel to direction of travel. Primarily, rotary hoes destroy weeds and grass around young plants or break up hard crusts (that hinder the emergence of small seedings) formed after a rain. In dryland farming, rotary hoes are found to be effective in breaking up clods and distributing bunches of straw. A rotary hoe pulled

backwards becomes useful as a subsurface packer or treader to tread down heavy stubble (Smith and Wilkes, 1976). The rotary hoe, either mounted or trailed, is a high speed implement usually operated between 8 and 13 km/h.

The skew treader is, in reality, a heavy duty rotary hoe with the gangs angled, or "skewed," much like gangs of an offset disk harrow. Like the rotary hoe, reversing the travel direction changes the tillage action obtained. Skew treaders were introduced into the U.S. Pacific Northwest in 1949 and have become important tools in trashy fallow tillage systems. They can be used for mulching stubble, spreading bunched crop residue, controlling weeds, and compacting seedbeds (Horning and Oveson, 1962).

Rod weeders have long been used in the U.S. and Canada for controlling weeds on summer fallow lands. The machine's soil engaging element, a rod, rotates just beneath, and parallel to, the soil surface as the unit moves through the field. Rods 22 to 25 mm square, or 25 mm diameter round rods, are used commonly. The direction of rod rotation, opposite to wheel rotation, brings clods and weeds to the surface where weed roots will be exposed to desication by air and sunlight. Rod rotation also helps firm loose seedbeds. Rod weeders effectively create a surface mulch and smooth the field. Rod weeders are considered a secondary tillage implement.

Early rod weeder models were driven by power applied at one end of the rod; newer models have center drive. Research in the U.S. suggests that end-drive rod weeders cannot be used satisfactorily when unmulched crop residue exceeds 1.7 t/ha. Center-drive units were used successfully in unmulched stubble up to 4.5 t/ha (Horning and Oveson, 1962). Ground or PTO-driven models are offered along with at least one hydraulic drive version.

Rod weeders are available as mounted or trailed implements. Gauge wheels control working depth of the rod. Best results with mounted rod weeders will be obtained when fitted with depth gauge wheels. "Bolt on" rod weeder attachments are available for chisel plows and field cultivators.

Repeated rod weedings can cause soil compaction interfering with the desirable tillage depth in subsequent operations. Under these conditions, shovels attached to a rigid bar mounted behind the revolving rod may be used. The shovels extend in front of the rod. This arrangement permits rod weeder operation in compacted soil or where subsurface ridges from previous tillage operations tend to lift the rod out of the ground (Horning and Oveson, 1962).

Rod weeders introduced in Turkey and other dryland farming areas are being widely used (Bolton, 1973; Bolton et al., 1971a; Hepworth et al., 1975). Rod weeder use should be restricted to relatively light soils. To reduce water runoff and wind erosion, rod weeders should be operated across slopes or at right angles to prevailing winds.

A major objective of a well managed dryland tillage system hinges on maintaining crop residues on the soil surface to improve infiltration and provide wind and water erosion protection. Data in Table 23 provides a means of comparing the reduction in crop

residues expected with use of various tillage tools (Jenkins and Jackson, 1970).

Selecting the proper combinations of implements as well as timing tillage operations are critical elements in dryland production. No single implement appears to be satisfactory for performing all the tillage operations required in dryland wheat production. Various combinations of implements and modes of operation have been tested. Combinations will vary from region to region depending on a host of factors.

B. Planting

The methods and equipment used for planting or seeding a crop greatly influence the yields produced. For maximum yields, consideration must be accorded factors such as planting of the seed, its germination, seedling emergence, and plant growth. Viable seed of a variety adapted to the particular geographical area should be planted at an appropriate date in a suitably prepared seedbed using approved seeding practices. Plants need protection from severe winter conditions and weeds that compete for moisture and nutrients (Kepner et al., 1978). Seeding practices become particularly important in regions with severely limited moisture.

Table 23 - CROP RESIDUE

Type of equipment	Expected amount or remaining residue to be covered in each operation (percent)
Straight blade sweep plow, 750 mm or wider	10
Straight blade sweep plow and treader	50
V-blade sweep plow, 800 mm or wider	10
Chisel plow, shanks 300 mm apart	25
Field cultivator, shanks 220 mm or less apart	20
Field cultivator, shanks 220 to 300 mm apart	25
Vertical disk plow, 50 to 80 mm depth	30
Vertical disk plow, 150 to 180 mm depth	70
Tandem disk harrow	50
Rod weeder	5 -- 10

Planting practices should provide for placing seed at a uniform depth in firm, moist soil. Planting depths usually range from 30 to 70 mm for winter wheat (Breece et al., 1975). Firming soil around the seed promotes moisture takeup by the seed and prevents seedlings from drying out. A ridged soil surface, or one roughened by exposed small clods and crop residues, affords plants some protection from cold winter winds and also helps control erosion.

A diverse collection of devices has evolved in man's search for effective ways to plant seed, insure good stand establishment, and increase crop yields. The dibble stick, or jab planter, is an example. In its simplest form, it is a pointed stick that is pushed into the ground to make a depression in the soil. The seed is placed in the hole by hand and covered, usually by foot. More sophisticated

forms utilize hollow sticks with some sort of automatic closing valve on the bottom to prevent the opening from becoming plugged with soil when the dibble is pushed into the ground. Seeds placed in the hollow stick are deposited in the ground when the stick is withdrawn (Van Der Sar, 1977). Units having 24 wooden pegs spaced 152 mm by 228 mm apart on a wooden frame are reported in use in northern India. Three people are required to operate this device. Two seeds are placed in each hole. Nearly 900 man-hours of labor are required to seed one hectare of land with this machine. Consequently, its use is limited to the planting of extremely small areas. An improved version having hollow teeth, seed hoppers, and drop tubes from the hoppers to the teeth requires only a two-man crew and has a field capacity double that of the original unit (Ojha, 1964).

1. Broadcast

Present day seeding methods include manual or mechanical broadcasting, various indigenous tools, or use of grain drills. Broadcast seeding may be accomplished by hand or by using broadcast seeding implements. This method requires little or no investment in equipment and can be performed under wet, rocky, or hilly field conditions unsuited to power-drawn seeding equipment. However, seeding rates and uniformity of seed distribution are difficult to control with broadcasting. Covering the seed requires a separate tillage operation which might involve use of a spike-tooth harrow or disk harrow operating at a shallow depth. Under these conditions, there is no assurance that seed will be covered uniformly nor placed on firm, moist soil. In most instances, higher seeding rates are needed with broadcast methods than with grain drills.

Broadcast seeding often associates with poor cropping practices and consequent low yields. For example, Goetze (1970) observed planting operations where land was moldboard or disk plowed, broadcast seeded, and plowed a second time to cover the seed. Hardly any condition known to promote good stand establishment was fulfilled by this system. However, broadcasting can be used effectively if the seedbed has been prepared properly and contains abundant moisture.

Equipment used for broadcast seeding ranges from a cloth bag or gourd used to carry seed while it is being distributed by the handfull, to mechanically-powered spin spreaders mounted on ground vehicles or aircraft. Hand broadcasting requires a skillful operator in order to achieve uniform seed distribution. More uniform distribution can be obtained using hand-powered spin seeders. A crank-driven, horizontally rotated disk scatters seed by centrifugal force. The seed is fed onto the spinning disk from a bag or a hopper carried by the operator. The spin seeder has an effective working width of approximately 8 m. Cross sowing--covering the land in two perpendicular directions and seeding with one-half the desired rate on each pass--yields a more uniform seeding pattern than just a single pass (Hopfen, 1969).

Tractor-powered broadcast seeders include centrifugal (spinning) or drop-type units. They are dual purpose machines as they can distribute dry granular agri-chemicals as well as seed. Centrifugal broadcast seeders are tractor PTO-versions of hand-operated spin seeders. Both mounted and trailed models are available. Hopper capacities on larger trailed units may exceed 4 m^3. Seeding widths

vary from 7 to 15 m depending on the unit and the crop seed being planted (Breece et al., 1976). Drop-type seeders, sometimes called full-width-feed broadcasters or end wheel spreaders, usually provide bands 2 to 4 m wide.

2. Drilling

Drill planting involves depositing seeds in shallow furrows (cut in the seedbed) and covering them with soil. A planting device unearthed at an archaeological site on the Indian subcontinent indicates that this method was practiced in the 2300-1700 B.C. era. The machine made 50 mm wide furrows spaced 300 mm apart (Steensberg, 1971). Similar devices are used today (Hopfen, 1969). Single-row versions of funnel-type seeders, so-called "country plow seeders," are also in common usage. These machines consist of a funnel and drop tube attached to an ard. Seeds are dropped into open furrows and covered by a drag device pulled behind the ard, or by soil from the furrow slice turn when the next furrow is made (Steensberg, 1971; Yadav and Singh, 1978).

Growers in the Lake Van region of Turkey use the TIR method of seeding. The TIR consists of a wooden, open-bottom vee, approximately 300 mm high and 2 m long, pulled by oxen. The implement carves a furrow about 250 mm deep depending on soil conditions. Seeds are hand-scattered in the vee as the TIR moves through a field. Soil closing in behind the TIR covers the seed to a depth of 80 to 100 mm. Fields planted with the TIR have produced five to seven times more grain than broadcast seeded fields. The TIR is used predominantly in light soils due to the limitations imposed by animal power. The animal-drawn TIR is similar to machines used in 1700 B.C. by the Sumarian civilization.

With the advent of tractor power, the TIR underwent modernization. Five-row, tractor-mounted versions are now used. Drop tubes and seed metering units similar to those found on grain drills have replaced manual scattering of the seeds. Theoretical field capacities of 1.5-2 ha/h can be achieved with operating speeds of 6-8 m/h (Ross, 1967).

Modern grain drills perform a series of functions by opening proper depth furrows, metering a controlled rate of seed, placing seed in the furrows, covering seed to the desired depth, and compacting the soil around the seed (Kepner, Bainer and Barger, 1978). Some grain drills have facilities for applying fertilizer concurrently with seed. Drill applying fertilizer at planting, besides reducing the number of trips across a field, can produce higher yields than when fertilizer is broadcast. This is particularly true for wheat sown in low phosphorus soils (Vavra and Bray, 1959). Grain drills do constitute capital investment in equipment. They also generate maintenance and repair costs and require a power source to pull them. Drill seeded fields, however, almost always produce higher yields than those broadcast seeded, even under poor seedbed conditions.

Both animal-powered and tractor-powered grain drills are used currently though the latter is increasing in use for dryland operations. Animal-powered grain drills may have one or more furrow openers. A single-row, pour-spout planter used in Pakistan has a fertilizer spout behind, and to the side of, the seed spout. Some

other animal-pulled units are equipped with a press wheel to more accurately control planting depth and to firm soil around the seed (CENTO, 1966). A more sophisticated machine used in India, has adjustable row spacing and a separate seed hopper for each furrow opener. A spring-loaded valve located at the bottom of each hopper and activated by a ground-driven lever system meters the seed (Parkhe, 1962).

Use of mechanical seeding devices reduces the labor required to establish a crop. Using a bullock-drawn, three-row drill with fertilizer attachment in 231 demonstrations conducted in eight Indian districts, an average of 17.55 man hours/ha were required to plant wheat. Traditional seeding methods averaged 61.71 man hours/ha. Use of the drill also required fewer hours of animal time per hectare (Rastogi and Mittal, 1975).

Several types of grain drills are available, each designed for a certain set of field conditions. Users need to evaluate these conditions when selecting a grain drill for a particular seeding operation. Grain drills can be classified as end wheel drills or press drills, depending on their construction. End wheel drills are supported by wheels at each end of the machine which also drive the drill's seed metering system. End wheel drills are also referred to as surface drills, regular drills, and normal drills.

Press drills derive their name from large press wheels behind each furrow opener. Press wheels support part of the drill's weight and also firm soil around the seed. Seed metering units on this type of drill are normally driven by the outside press wheels. Other names sometimes associated with the press drill include deep furrow drill, press wheel drill, lister drill, mulch hoe drill, and plow press drill.

One of the critical field conditions that affects drill selection is the distance from ground surface to moist soil at planting time. Generally, end wheel grain drills are not used unless ample moisture exists within 50 mm of the soil surface. However, excessive crop residue on the soil surface can render an end wheel ineffective despite the moisture level (Breece et al., 1975).

Row spacing, another factor to consider, is determined by annual precipitation, crop growth habit, amount of residue on the land, type of opener required to place seed in moist soil, and amount of ridging necessary to protect against winter weather and erosion. Row spacings commonly used in end wheel drills include 152, 178, and 254 mm. Typical press drill spacings are 152, 178, 254, 305, 356, and 406 mm. The 305 and 356 mm spacings are common in 400 mm rainfall areas (Horning and Oveson, 1962).

Either disks or shovels are used to open furrows to the desired seeding depth. Choice of opener for a given condition should consider depth to moist soil, soil surface residue, desired row spacing, and the presence or absence of rocks or other obstacles (Breece et al., 1975).

Relatively shallow planting, to a maximum depth of 100 mm below soil surface, favors use of disk openers. The concave blade of single disk openers suits hard or trashy soil conditions. Double

disk openers, having two flat blades, need well prepared, residue-free seedbeds to operate effectively. Double disk openers plant at more uniform depths than single disk openers, particularly at faster travel speeds.

Shovel-type openers are normally used for rough and rocky soil conditions. Often they are equipped with spring-trip or breakaway mechanisms to protect against mechanical damage. Shovel openers can be used for shallow planting, but are required for deep seeding operations. Shovels from 44 to 230 mm wide are available to meet various seedbed conditions. Disk and shovel openers may be used on both end wheel and press drills. Wider shovels, however, are used exclusively on press drills (Breece et al., 1975).

Seed coverage and soil compaction are important for reducing evaporation and increasing moisture absorption. Soil that falls back into a furrow after a furrow opener passes may or may not provide desired conditions. Drag chains pulled behind each opener often help cover the seed. Their use best suits moist seedbed conditions where very little soil compaction around the seed is needed. Press wheels behind each furrow opener create desired soil compaction under dry seedbed conditions where drag chains are ineffective. High moisture seedbed conditions necessitate using press wheels with care to avoid soil over-compaction which can deter germination and emergence.

Special equipment and techniques are required for dryland seeding when moist soil is well below the surface. Grain drills used for deep seeding, often referred to as deep furrow drills, essentially are press drills capable of operating at greater depths than ordinary end wheel drills. Shovel openers displace surface dry soil laterally into ridges between drill rows allowing for seed placement in moist soil at the furrow bottom. Assuming a 100 to 150 mm deep dry soil layer and seed placement 25 to 50 mm into the moist soil, the total operation would be 150-200 mm below the undisturbed soil surface.

Deep furrow drills may have row spacings up to 406 mm, thereby exceeding the maximum end wheel grain drill row spacings (Breece et al., 1975). Wider row spacing can evoke criticism from uninformed farmers because of "wasted space" between rows. It is not always well understood that wider row spacings are required for deep furrow seeding to provide sufficient space to store the displaced dry soil (Goetze, 1971). Deep seeding with close row spacing usually causes excessive soil to fall back into the furrow burying seed under too much earth to realize optimum germination and emergence. Press wheels are used to compact the soil around the seed as in regular seeding operations. Specially shaped wheels are available which also firm the furrow walls to reduce soil sloughing.

Two conditions must exist for deep furrow drilling to have any significant advantage over other types of grain drilling. First, sufficient moisture should be available at the seeding depth. Second, planting must be performed well before winter so plants develop sufficient root systems and become well tillered before entering winter dormancy. Deep furrow drills can be operated at shallow depths but offer no significant advantage over other drill types when seed is placed in dry soil. The ridged soil surface, however, may help control wind and water erosion and provide plants with some protection

from severe winter conditions (Pumphrey et al., 1975). Deep furrow drills have higher draft requirements than other drill types because a greater volume of soil is moved during seeding.

For seeding in residues, deep furrow drills equipped with shovel openers function admirably. Drill must meet the following specifications: 260-360 mm row spacing (wider spacing in heavy residues); 510 mm minimum clearance between opener shanks; 460 mm minimum vertical clearance between frame and opener bottom; 100 mm maximum opener width; and press wheels that pack seed firmly in the soil and anchor residues in the ridge. Many firms manufacture deep furrow drills that meet these requirements. A drill can be fitted with a wide variety of shovels and press wheels to meet specific soil or climatic zone needs.

Conventional seeding (and tillage) implements may not be sufficiently rugged to withstand the adverse working conditions imposed on them by shallow, rocky soils encountered in some dryland farming regions. Low effectiveness, high breakage, and excessive maintenance and repair costs result. Survival under these conditions requires extra-heavy construction, high underframe clearance for clearing obstructions, and suitable safety trip mechanisms to reduce breakage of implement components when an obstruction is encountered. Hafiz (1974) observed that numerous Australian implements developed on the "stump jump" principle are among those fulfilling these conditions.

Grain drills, like any other farm implement, are designed to perform certain functions. How effectively these functions are carried out depends, to a large extent, upon the knowledge and skill of the operator. Seeding at the desired rate and depth are possible only if the drill is properly maintained, correctly adjusted, and operated in a judicious manner.

C. Weeding

Weeds tend to be both prolific and persistent. They negatively affect crop production by increasing labor requirements and production costs, subduing yields, and quite possibly reducing quality of harvested products (Hughes, 1976). In some situations, weed root systems and vegetative cover provide wind and water erosion protection, or serve as a source of animal feed. But for dryland farming, where moisture conservation is paramount, weeds agressively compete for the already limiting soil moisture and nutrient supplies and need to be controlled. In 1973, for example, Guneyli estimated that weeds reduced Turkey's wheat production by 27 percent (Pumphrey, 1975).

Weed control methods embrace a variety of techniques. Cultural, including both manual and mechanical, chemical, and biological control can be employed, depending on conditions, alone or in combination. In dryland farming, predominant control practices include cultural--tillage, planting weed-free seed, crop rotation, livestock grazing, hand weeding--and chemical, the use of herbicides.

1. Control by tillage

Tilling the soil controls weeds by uprooting plants, thereby separating root systems from the soil and causing desiccation. Or, the weed stem or stalk may be severed just below the ground surface. Covering weeds' aerial, or above-ground segments, with soil can smother and kill plants.

Tillage can be practiced effectively on fallow land and in row crops with sufficient room for equipment to function without damaging crop plants. However, in established broadcast crops, or in close-spaced rows, weed control via tillage is precluded.

Hand methods of weed control practiced include pulling weeds, and using hoes or hand cultivators (Hopfen, 1969). If properly scheduled, hand weeding can control annual and biannual weeds, but not perennial weeds. Hand methods involve arduous physical labor while being extremely time consuming (Pumphrey, 1975). Manual methods also have potential for causing undesirable effects. Hoeing can disturb fallow land soil mulch or damage the root systems of established crops (Misra and Cixit, 1965).

Except for primary tillage, weed control normally involves shallow tillage operations. Many of the same implements used for shallow primary tillage and for secondary tillage also perform a weed control function. Commonly used animal-drawn and tractor-drawn implements include the chisel plow, sweep plow, field cultivator, vertical disk plow, tandem disk harrow, rotary hoe, and rod weeder. Sweep-equipped implements are used widely because of their ability to cut off weeds while leaving the soil surface essentially undisturbed, thereby minimizing moisture losses.

Tillage treatments tend to be site specific. For example, trials conducted in Nebraska (U.S.) using a stubble mulch system of farming revealed that optimal weed control occurred when tillage sequences included use of a vertical disk plow. The sequence of tillage operations had greater influence in dry years than when moisture was plentiful (Fenster et al, 1965). Disk-type implements, because of their tendency to expose moist soil and accelerate evaporation losses, require judicious use. In stubble mulch farming systems where surface residue preservation is emphasized, using disk-type implements beyond the initial tillage operation is not recommended if the residues are less than 2.25 t/ha (Horning and Oveson, 1962).

Land is fallowed, in dryland systems, for one main purpose: moisture conservation. Allowing weeds to grow on fallowed land, and "pump" water out of the soil, is self defeating. Weed control programs are required. The number of operations required will depend on frequency and amount of rainfall following the first spring tillage. Rod weeders and sweep-type machines are among the most satisfactory tillage tools for weed control in the U.S. Pacific Northwest (Horning and Oveson, 1962).

2. Control by chemicals

Herbicides add strength and flexibility to a farmer's weed control program. They expand the range of weed control methods available

compared to cultural practices alone. Preemergence herbicides in dryland farming help a crop to become established without competition from weeds during the initial growing stages. Chemical control can be used to control weeds in crops where cultivation is not possible. In established crops, selective herbicides reduce the need for weed controlling tillage operations. A chemical component can control weeds, primarily perennials, which are difficult or impossible to control with normal cultural practices.

Herbicides can be selective--only lethal to certain plants--or nonselective, and either contact or systemic. Contact materials affect only the plant parts treated while systemic compounds are absorbed by plant roots or foliage and translocated throughout the plant. Herbicides are used as liquid sprays or dry granules. Application patterns include banding, broadcasting, spot treatment, and directed sprays. Depending upon the particular material, herbicides may be applied before a crop is planted, after it is planted but before it emerges, or after it emerges (Hughes, 1976; Pumphrey, 1975).

Herbicides applied as liquid sprays may be in soluble, emulsifiable concentrate, or wettable powder form. Each formulation requires different spray equipment. Solutions are easiest to handle because the herbicide's active ingredient is soluble in water or other appropriate carrier. Using clean water and carefully maintained sprayer strainers and screens minimizes nozzle plugging and wear. An emulsion, one liquid suspended in another liquid, requires agitation to keep the emulsified concentrate in suspension. Wettable powders are the most difficult class of herbicides to handle because they require constant agitation (to keep them suspended) and their abrasive nature accelerates nozzle wear. The person applying herbicides needs to know their characteristics and properties as well as spraying equipment capabilities. Otherwise, less than desirable, or even hazardous, conditions may result. Successful chemical weed control depends upon using the proper herbicide in the correct amount, at the correct time, applied to the correct target (Hughes, 1976).

A variety of equipment is used to apply liquid herbicides. Small, hand-operated, compressed air sprayers and gasoline engine-driven knapsack or backpack units having one or two nozzles and tank capacities of a few liters are suitable for spot treatments and for small areas inaccessible to larger equipment. Tractor-mounted, trailed, and self-propelled units with multi-nozzle booms are used for larger areas. Tractor-mounted sprayers, with tank capacities of 200 to 2,000 liters, may be used independently or in conjunction with tillage and planting equipment. Some larger self-propelled sprayers have 15 m booms, or longer, and tank capacities upwards of 10 kL. Aircraft-mounted sprayers are also used (Hughes, 1976) for treating large areas. A self-propelled sprayer with high flotation tires and 19.5 m spray boom has an effective field capacity of approximately 28 ha/h. On the same farm, aircraft applications covered 60 to 100 ha/h (Keil, 1970).

Herbicide granules may be applied in a band(s) or broadcast. Operator-carried units are available for either application system and also for spot treatment. Animal-drawn equipment exists, but the most common units for treating larger areas are tractor-mounted, or trailed, granule applicators. A drive-and-metering system distributes the desired amount of herbicide per meter travelled from

storage hoppers. Some granular herbicides require incorporation. An incorporating implement has to follow the applicator, either on the same trip or as a separate operation. Spin spreaders employ one or two horizontal rotating disks to impart centrifugal force to granules fed from a conical hopper. Granules are spread over the ground surface in a semi-controlled swath.

Both cultural and chemical weed control methods have advantages and drawbacks. Frequently, an effective dryland weed control system includes the coordinated and integrated use of cultural practices as well as herbicides.

D. Fertilizing

Manufactured fertilizers continue to supplant use of manure in dryland farming regions. Where manure is available--and not a vital source of fire fuel--spreading may take place by hand, or by use of animal- or tractor-drawn equipment.

Some of the same kinds of spray equipment used for applying herbicides are used for surface applications of liquid fertilizers (as well as liquid materials for insect and disease control). Subsurface applications of liquid (ammonia) fertilizers, however, require a furrow opening device. Commonly these include injector blades or knives, disks, and cultivator shovels. Liquid fertilizer is metered into the furrow through injector tubes and the furrow immediately closed to minimize loss of volatile materials (Hughes, 1976).

Anhydrous ammonia (NH_3) and aqua ammonia (NH_4OH in water) are the two liquid N fertilizers that require subsurface applications under all conditions to prevent direct volatilization loss of NH_3. Nitrogen fertilizers that supply the ammonium (NH_4) form of N are subject to volatilization losses of NH_3 when broadcast and left on the surface of calcareous soils. These problems are more critical with urea than with other materials. To date, little or no use has been made of anhydrous and aqua ammonia in the LDC's.

A liquid fertilizer applicator may use gravity, pump, or compressed gas to move the liquid from its tank to the individual openers, depending upon the type of material involved. Gravity systems are used for both surface and subsurface applications. They are the simplest, least expensive, and also the least accurate because of pressure changes that occur as the liquid level in the tank changes. Urea in water would be a typical example of a material applied using a gravity flow system. Metering orifices in standard spray nozzle bodies are used to control the flow. In systems using engine driven pumps, application rates are a function of the speed of travel as well as the operating pressure. Compressed air can be used to force liquid fertilizer material out of the tank in the same manner used for weed sprayers. However, in the case of anhydrous ammonia, the vapor pressure of the ammonia gas held in the head space of the tank is used to force the liquid through the distribution system (Hughes, 1976).

Spin spreaders and drop-type distributors apply granular fer-

tilizer in similar fashion to granular herbicides. Band applicators place dry granules in narrow bands either on, or below, the soil surface. Sub-surface application requires a furrow opening device which may be a shovel, disk, or other placement device. This type of dry chemical applicator is frequently used as an attachment for some other implement such as a grain drill. Separate drop tubes for the seed and the fertilizer permit the use of a single furrow opening device, but placement of the seed and fertilizer at different locations. Both fixed-wing aircraft and helicopters are used for aerial broadcasting operations.

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IX. RANGELAND RESOURCES

A. Rangeland: What and Why

Large sections of the world's land surface endure physical conditions that either severely limit or totally rule out cultivation. Whether due to low and erratic precipitation, rough topography, non-arable drainage, low temperatures, or a combination, these areas classify as rangeland. Approximately 47 percent of the earth's land surface is rangeland (Williams et al, 1968).

Substantial portions of all major continents are rangeland. More than half a billion hectares in the U.S.--54 percent of the land area of the 48 contiguous states--can be classified as rangeland (USDA, 1974). Africa and the Near East contain the world's largest expanse of arid and semi-arid rangeland, totaling some 7 million km^2 (FAO, 1974).

Rangelands are composed of grasslands, savannahs, brushlands, open forests, tundra, and marshes. They supply forage for free ranging native and domestic animals; they also provide a source of wood products, water, and wildlife (Stoddart, et al., 1975). Production per unit area often is limited, but total revenue from range areas contributes substantially to the economies of many countries. Although their main product is red meat, rangelands also yield water, fuel, building materials, minerals, medicinal and food plants (FAO, 1974), and recreation.

In developing countries of the Near and Middle East and in North Africa, rangelands provide principal sustenance for over 200 million head of domestic livestock (FAO, 1974). Natural forage from rangelands amounts to nearly 70 percent of the total feed requirements of livestock in Iran each year. This amounts to some 80 million sheep units* of feed annually (Shaidaee, 1974). In Australia, rangeland supports one-third of the cattle and sheep population (Box and Perry, 1971). One expert estimates, that in the U.S., 54 percent of feed units consumed by all livestock and 76 percent of feed units consumed by beef cattle come from forage (Hodgson, 1972).

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* The various classes of livestock have been converted to sheep units on the premise that one sheep equals one sheep unit, one goat equals 0.7 sheep unit, one cow equals 55 sheep units, etc.

1. Historic outlook

The earliest written record of man contains strong evidence of a close relationship between man and beast. Evidently grazing of domesticated animals occurred as early as 9000 B.C. (Stoddart et al, 1975). Goats were well established in the Middle East in 7000 B.C. and sheep about 1000 years later. Cattle were present in Greece by 6200 B.C. and horses and asses probably somewhat later. These animals were widespread from the Nile to the Indus 5000 years ago (Pearse, 1971). Although pastoral culture patterns varied from place to place, a common element emerged, best described as man (in nature) striving to live harmoniously with his surroundings, not for the sake of conservation, but for survival (Stoddart et al, 1975).

Although livestock have been grazing for over 9000 years, efforts to scientifically manage this activity began less than half a century ago in less developed countries (Whyte, 1961). In the early 1950's the first range technicians in Middle Eastern countries found widespread range depletion and serious soil erosion. All blamed centuries of continuous overgrazing and land abuse (Schwan, 1954; Kerr, 1955; and Stewart, 1955). Recent studies throughout the region however suggest that most of the range deterioration may be relatively recent (Pearse, 1970). Anthropologists believe that historically, internal strife--recurrent raids, invasions, and warfare--as well as natural disasters effectively limited the number of people and their animals so that seldom could they destroy their environment (Whyte, 1961).

Not until the late nineteenth century and the establishment of greater stability did nomadic and especially semi-nomadic flocks, increase. In portions of Pakistan, animal units have increased five-fold in the past 100 years (Lodge, 1965). Records reveal a doubling of livestock numbers in Iran between 1901 and 1951 (Pearse, 1968) and a second doubling between 1952 and 1962 (Shaidee, 1974). Grazing pressure in 1974 for Iran was estimated to be four times the grazing capacity. Total livestock numbers tripled in Egypt between 1955 and 1967 (Pearse, 1970). Although the accuracy of these figures may be challenged, the trends clearly indicate that massive increases in livestock numbers have occurred throughout the Middle East and Northern Africa in the last three to four decades.

Increased livestock numbers, however, do not shoulder sole blame for the present rate of rangeland deterioration. Increased human populations and subsequent food shortages have caused a cultivated area expansion in nearly all developing countries. The result: a reduction of hectares available for animal grazing and severe erosion problems. Tisdale (1967) reported that Turkish rangeland area shrunk 50 percent during 1944-1962 and that two-thirds of these lands were not suited to cultivation. Iran increased rainfed lands growing cereal three to nine times during the 1960's. As a consequence, an estimated 11 percent of current Iranian rangelands consist of land abandoned from cropping. Similar events, plowing land better left as range, has been reported for other countries by Tisdale (1967), Bailey (1967), and Awad (1962).

Fuel gathering also has contributed accelerated rangeland

deterioration in many countries. The practice involves harvesting and burning shrubs as a domestic fuel in village kitchens. Left in place, these shrubs protect against soil erosion and often provide food for animals.

Finally, a steady shift from nomadic to sedentary grazing has accelerated range deterioration by concentrating once nomadic flocks in areas adjacent to villages.

Evidence suggests that rangeland has been misused in most developing countries for centuries and that the destructive processes have acclereated during the past few decades. Negative impacts affect not only livestock owners, but urban populations as well through increased floods, dust storms, moving sand dunes, and siltation of irrigation works (Pearse, 1970).

Many rangelands in industrialized nations, on the other hand, are beginning to reflect a stable or upward trend in range condition. Unlike their counterparts in most developing countries, rangelands in the U.S. have been used by livestock for little more than one century. Most U.S. range abuse took place during the late 1800's and early 1900's, a period of high domestic animal use and little applied management. An interest in land conservation, plus development of new technologies and management organizations, soon spawned the new scientific field--range management. Education, research, land policies, and a general public interest greatly affected the course of this field.

Many technologies developed in industrialized nations are applicable to, and are being used by, less developed countries of the world. Through worldwide education and training programs, people in the field of range science now have an unequalled opportunity to assist in the world food crisis and at the same time protect rangelands from further degradation.

2. General concepts and terminology

Through the process of photosynthesis, plants manufacture and store more food than they normally use. Animals can be allowed to utilize this excess reserve material, under appropriate grazing systems, without damage to the plant or rangelands. All rangeland plants can be grazed to some degree; in fact, light or moderate use may stimulate growth of some species (Heady, 1975). The science and art of proper management hinges on knowing how much material can be removed from each plant species without initiating a downward trend in range condition. Season (time of year), intensity (percent removal), and frequency of grazing (interval between grazings) all influence a plant's tolerance to defoliation. Additionally, site characteristics such as soil moisture, soil depth, and available nutrients affect a plant's response to grazing.

All animals are selective in the plant species they graze. Plant species most highly preferred, based on their reaction to grazing, are defined as decreaser species--species present in the original plant community which decrease with increasing grazing pressure. Reduced numbers of these species provide initial evidence of a downward trend in range condition.

Species present in the original community which are secondary in preference are classified as increasers. These plants become more abundant with increased grazing pressure, at least for a time. Invaders constitute a third category of plants, based on reaction to grazing. These species were not present in the original community, but opportunistically move into gaps left as more palatable species are removed. Defining a plant as an increaser or decreaser species depends on the particular animal species grazing it, the season of the year it is used, and the ecological features of the site on which it is found.

Ecological range condition is evaluated on the basis of erosion evidence and on the observed changes in relative amounts of decreaser, increaser, and invader species. Consequently, proper use of a rangeland must take into account animal selectivity and the tolerances of species on a particular area in a given season of the year.

B. Range Plants: Physiology

1. Photosynthesis

Rangeland managers need a basic understanding of photosynthesis since this chemical process forms the basis of plant growth and production. Photosynthesis is the biochemical process of carbohydrate synthesis (CO_2 fixation) through the use of solar energy, a light trapping process directly or indirectly essential to almost all forms of life. The surrounding environment influences rates of photosynthesis (Helms, 1972). Four important environmental factors affecting this chemical process are moisture availability, light, temperature, and carbon dioxide levels.

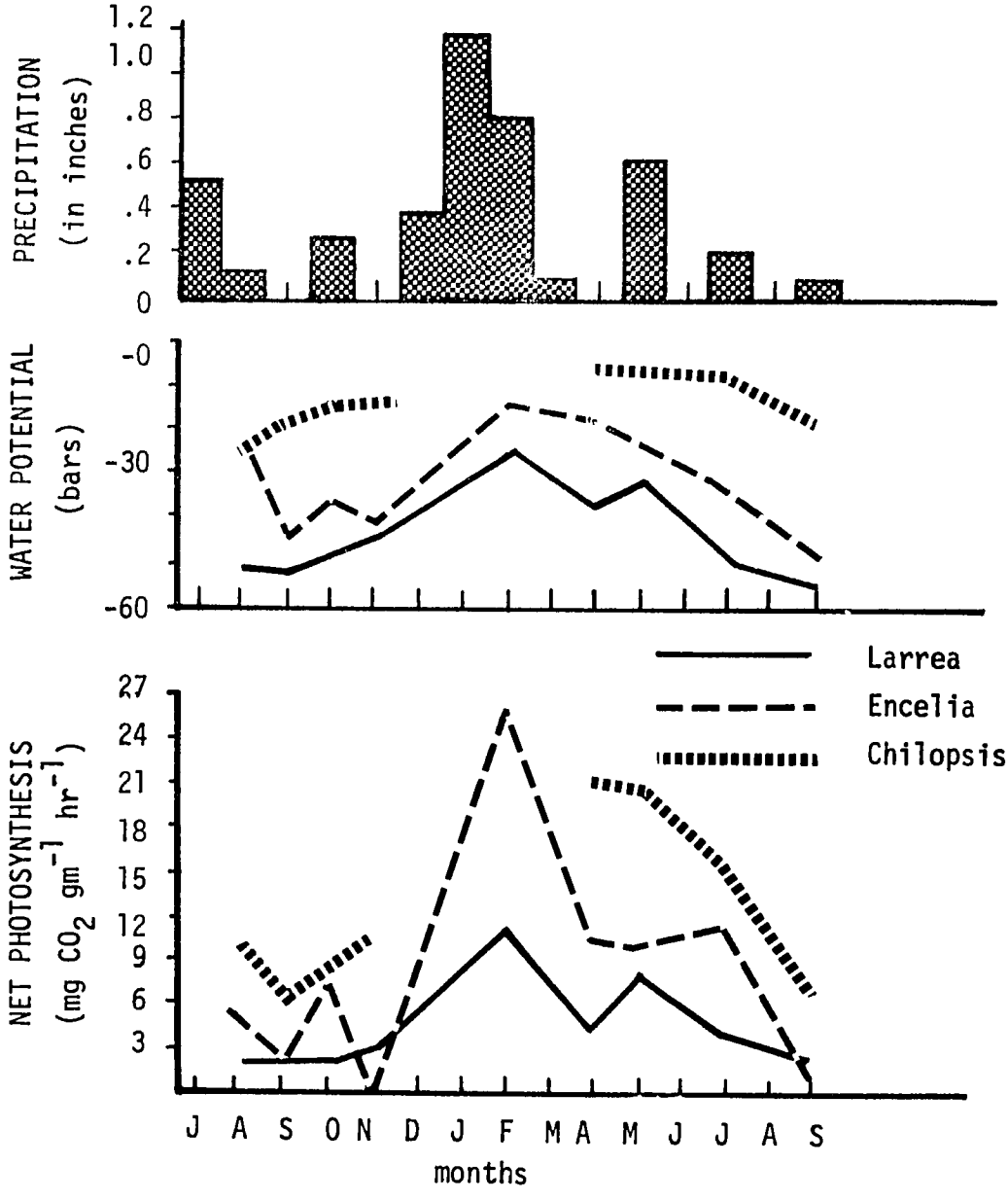
Water availability most frequently limits plant growth on rangelands. Depuit and Caldwell (1973) found seasonal patterns of photosynthesis in big sagebrush (Artemesia tridentata) directly correlated with available soil moisture. Photosynthesis rates were highest in May and early June when moisture availability reached a seasonal maximum, and lowest in August during minimum moisture availability. Odening et al. (1974) found photosynthesis rates of two other desert plants peaked during winter's maximum precipitation (Figure 15). A third species, Chilopsis linearis, remained dormant during the cool, wet months; it was adapted to photosynthesize during warmer and drier conditions. Morrow and Mooney (1974) reported that photosynthesis and soil moisture had a higher correlation than photosynthesis and plant water potential.

Photosynthesis does not increase directly with soil moisture after drought. The rate of recovery in photosynthesis following water stress was greatly influenced by the root system (Brix, 1962). The slow recovery of photosynthesis following drought probably was due to decreased capacity of roots to absorb and conduct soil moisture.

Temperature effects photosynthesis by controlling chemical reaction rates and plant water potential. Under optimum environmental conditions, a strong relationship exists between net photosynthesis

Figure 15 - MOISTURE AND PHOTOSYNTHESIS

Seasonal patterns in precipitation (monthly total), maximum (dawn) water potential, and maximum net photosynthesis rates for 1968-1969, Chilopsis linearis was leafless from December through March.



and temperature (Helms, 1972; Hari and Luukkanen, 1974). DePuit and Caldwell (1973) reported that in spring and early summer, during minimal plant water stress, photosynthesis rates in big sagebrush mainly correlated with leaf temperature and sunlight. As moisture potential decreased, correlation between photosynthesis and temperature dropped.

Under favorable conditions most temperate plant species utilize approximately one percent of the gross solar energy for primary production (Odum, 1971). Light saturation levels vary widely among species. Although light saturation for a single leaf occurs at radiation levels far short of full sunlight, arrangement of leaf blades and stems in the field often causes a considerable inner portion of the plant to be short of light (Chang, 1968).

Photosynthesis potential also changes with plant growth stage. DePuit and Caldwell (1973) measured photosynthesis rates during five growth stages in big sagebrush and noted that potential for CO_2 fixation peaked during vegetative stages. As soon as reproduction began, photosynthesis rates rapidly declined. Leopold and Kriedemann (1975) reported photosynthesis rates increased with leaf growth until leaves reach full size then decreased. Limited moisture retards the CO_2 fixation process.

Another phenomenon, optimum temperature levels for photosynthesis, changes with plant maturity (DePuit and Caldwell, 1973). Optimum temperature for big sagebrush changed from 15°C in the early growing season to 20°C as plants matured. This species exhibited increased ability to tolerate high temperatures later in the growing season.

2. Plant food reserves

Total available carbohydrates refer to the energy reserves utilized by a plant. Roots, tubers, stem bases, stolons, corms, and rhizomes store carbohydrate reserves (Cook, 1966). Synthesized by the leaves, storage reserves are later mobilized for plant use. Carbohydrate reserves are used primarily during periods of rapid growth, initial growth, growth or respiration during the winter, and for replacing defoliated tissue (Troughton, 1957).

Total available carbohydrates tend to be high immediately following snow disappearance, then rapidly decline during leaf and flower stalk formation, rising to a second peak near the end of the growing season (McCarty and Price, 1942). Menke (1973) reported levels of carbohydrates were inversely related to growth rate. Initial growth of both herbage and roots during early growing season stages consumed approximately 70 to 75 percent of the carbohydrate reserves stored during the previous growing season (McCarty and Price, 1942; Troughton, 1957; Priestley, 1962). Woods et al. (1959) reported that carbohydrate reserves contributed 40 percent of the material used for leaf growth. Carbohydrate reserves ceased to decline when 10 to 45 percent of the annual growth had been produced (McCarty, 1938; McCarty and Price, 1942).

Menke (1973) reported that plant crowns contained consistently higher concentrations of total available carbohydrates than roots throughout the growing season. Seasonal changes in reserve levels in the roots of bitterbrush (*Purshia tridentata* Auth.) were much greater than in its aboveground tissue (McConnell and Garrison, 1966).

3. Morphology and adaptability

Morphological characteristics of grass plants influence how they respond to management of their environment. Grasses having a high proportion of vegetative stems exhibit more resistance--and often increased production--under grazing pressure by delaying elevation of their apical bud or sprouting freely from axillary buds (Stoddart et al., 1975).

Grasses can be separated by the presence of culmed or culmless vegetative shoots (Hyder, 1972). Culmed and culmless shoots are determined by internode elongation. Generally only the uppermost three or four internodes elongate.

The major challenge facing management of rangelands arises from the predominantly arid to semi-arid conditions that prevail. The adaptability or ecological success of certain plants to efficently acquire and utilize local supplies of moisture becomes the prime concern. Xerophytic (drought tolerant) plants have evolved morphologically and biochemically to carry on photosynthesis in very dry environments. Morphological adaptations such as deep root systems, small thick leaves, protected stomatal aperatures, and leaving only during periods favorable to photosynthesis enable desert plants to maintain sufficient water potentials under xeric conditions (Meidner and Mansfield, 1968; Morrow and Mooney, 1974; Odening et al., 1974).

Gates (1975) reported that small leaves are more adapted to deseritic conditions than large, broad leaves. Small leaves have lower transpiration rates due to a higher boundary resistance layer; they also demonstrate an increased level of heat loss, resulting from higher convection potential, an important ability in environments with high air temperatures.

Increasing the productivity of a specific site involves considering the initial stage of dry matter production. The ability of a plant to efficiently maximize production depends upon the physiological capabilities of the plant and the environmental factors characterizing the site.

C. Range Plants: Defoliation

1. Defoliation

The terms plant vigor or health are used frequently in discussing plant response to grazing. However, neither can be directly measured and are thus evaluated by measuring other plant parameters--total available carbohydrates, production, crown diameter, culm numbers, and percent viable seed.

Trlica and Cook (1972) reported that carbohydrate reserve levels at the end of the growing season was a reliable indicator of defoliation effects on the plant. Fall carbohydrate levels closely correlated with the following season's production potential (Sampson and McCarty, 1930; McCarty and Price, 1942). A reduction in fall storage levels reduced plant growth in the spring (McCarty and Price, 1942). Also, carbohydrate levels maintained through the winter appeared to

affect winter hardiness (Kust and Smith, 1961). As the effect of defoliation increased due to season, frequency, and intensity of clipping and/or climatic stress, total available carbohydrates decreased (Cook, 1966; White, 1973; Trlica, not dated).

When green leaf tissue had been removed, carbohydrate reserves were translocated from the roots and crown to aboveground meristematic regions for regrowth of new leaf tissue (Troughton, 1957; Davidson and Milthorpe, 1966b; Ehara et al., 1967). Donart and Cook (1970) reported that root reserves of some grasses and forbs continued to decrease after clipping until approximately 20 percent of the regrowth was produced. Two important plant factors affecting regrowth potential were carbohydrate reserve levels prior to defoliation and leaf area remaining after clipping or grazing (Donald and Black, 1958; Ward and Blaser, 1961).

As the severity of herbage removal increases, production decreases (Reed and Peterson, 1961; McKell et al., 1966; Mueggler, 1967). Reed and Peterson (1961) reported that changes in basal area, growth habit, and other vegetative characteristics caused by grazing were reflected in herbage yield.

Sometimes several seasons may pass before plants show any measurable response to treatments (Mueggler, 1967). Some investigators have reported clipping increased herbage production (Albertson et al., 1953). However, the higher level of production was often due to an increase in undesirable species (Schuster, 1964).

A major problem in evaluating plant response to defoliation is year-to-year variability that can obscure treatment effects. Trlica (not dated) states, "A plant will react differently to grazing pressures, depending upon climatic conditions, range site and condition, kind of herbivory, season of use, and frequency and intensity of herbivory." Other workers report that defoliation usually affects plants more severely during low rainfall years (Hyder and Sneva, 1963; Sosebee and Wiebe, 1971).

2. Season

For desert forage species, the season of herbage removal often has a greater effect on plant vigor than the intensity of removal (DeBano, 1957). Season of use can be defined as the stage during which a plant is defoliated. Most researchers agree that season has a definite effect on the severity of defoliation, but cannot fully agree as to which growth stage is the most sensitive to defoliation. Most, however, believe that late flowering to senescence includes the critical period and that defoliation during late senescence, dormancy, or early spring is least detrimental (Sampson and McCarty, 1930; McCarty and Price, 1942; Mueggler, 1967; Cook, 1971; Drawe et al., 1972; Trlica and Cook, 1972; Menke and Trlica, 1972 and 1973).

Maximum plant root growth activity generally occurs prior to, and during, very early vegetative activity (Roberts and Hunt, 1936). Defoliation during early growth stages can significantly retard root development (Albert, 1927; Hyder and Sneva, 1963). Plants clipped late in the growing season produced the highest yield, but lowest carbohydrate reserve levels (Cook et al., 1958). End-of-

season clipping on true prairie reduced herbage yield by one-third the following year compared to unclipped plants (Anderson, 1960).

Carbohydrate reserves generally do not begin to accumulate until the growth rate of aerial plant parts decreases or terminates (Sampson and McCarty, 1930; McConnell and Garrison, 1966). Some researchers believe that the adverse effects of defoliation result from low carbohydrate reserves at the time of herbage removal (Craddock and Forsling, 1938; Hedrick, 1958). However, this is also the period just prior to rapid carbohydrate accumulation (McCarty and Price, 1942; Brown and Blaser, 1965; McConnell and Garrison, 1966). As the growing season progresses, the regrowth potential of photosynthetic tissue decreases (Blaisdell and Pechanec, 1949; Donart and Cook, 1970). The amount of reserves stored during the period of accumulation is a function of the leaf area or photosynthetic tissue present (Sullivan and Sprague, 1943; Donald and Black, 1958; Ward and Blaser, 1961). When environmental conditions extended the growing season into the fall, substantial regrowth after late defoliation enabled carbohydrates to accumulate to normal levels (McCarty and Price, 1942).

3. Intensity

Intensity of defoliation affects a plant's response to herbage removal. Heady (1975) defines defoliation intensity as "the degree to which herbage has been removed." Range managers often think of intensity as the percent (or weight) of annual forage production consumed or destroyed. Food reserves, vegetative production, basal area, cover, and flowering all respond to intensity of defoliation. As defoliation intensity increases, carbohydrate levels (Weinmann, 1948; Kinsinger and Hopkins, 1961), production (McCarty and Price, 1942), basal area (Paulsen and Ares, 1962), cover (Nelson, 1934), and flowering decrease (Valentine, 1970). Underground plant parts also react to intensity of herbage removal; as defoliation intensifies root growth slackens (Crider, 1955) and, in severe cases, root die-back increases (Sampson, 1914). Crider (1955) found that the percent of top growth removed determined whether roots stopped growing and for what duration. Greater root depth on moderately grazed pastures than on heavily grazed pastures has been reported (Schuster, 1964).

Defoliation intensity relates to the amount of green leaf and stem tissue remaining after clipping. The amount or level of photosynthetic tissue left after defoliation determines leaf efficiencies, initial rates of regrowth, time required to reach maximum regrowth, and carbohydrate levels (Brougham, 1956; Garrison, 1972; Sullivan and Sprague, 1943; Sampson and McCarty, 1930).

4. Other factors

Plant production, tiller numbers, and carbohydrates generally decreased as frequency of defoliation increased (Owensby et al., 1974; Beatly and Powell, 1976). Levels of total available carbohydrates stored at quiescence either depended on the number of defoliations during the growing season, or were inversely proportional to the time span between defoliations (Thaine and Heinrichs, 1951; Thaine, 1954). Although increased frequency of defoliation reduced total yield, leafiness and nutrient quality increased because of

renewed young growth. (Cook et al., 1958).

Plant morphology affects the impact of defoliation. The ability of grasses to resist grazing increases with basal meristems, tuft bunch or rhizomatus growth habit, high potential for basal bud development, and a low ratio of reproductive to vegetative stems (Branson, 1953; Rechenthin, 1956). Meristematic tissue location appears to determine susceptibility of grasses to grazing injury (Branson, 1953). The higher the growing point above ground, the more easily it is removed by grazing thus affecting plant response more than on a culmless species. Apical meristems should be retained on the plant to maintain stem elongation and leaf expansion (Hyder, 1972).

Tillering can increase or decrease depending on time of defoliation. Herbage removal during early vegetative development decreased tillering while defoliation later in the season increased tillering (Hyder, 1972). By removing elongated culms or the inflorescence and peduncle, tillering increased due to activation of basal axillary buds. Lateral bud growth is significantly increased by removal of the terminal bud during dormancy on several shrub species (Garrison, 1972). However, flower and seed production decreased on shrubs that set flower buds during the previous growing season. Defoliation of stem apices removes apical dominance which releases lateral bud growth (Leopold and Kriedemann, 1975).

Heavy defoliation--leaving little residue behind to carry through the winter--can be very detrimental to the plant. Many grass species have the potential of producing phytomers during the autumn which remain dormant during the winter and produce early spring shoots (McCarty and Price, 1942). Removing stubble exposes these shoots to cold winter temperatures.

Leaf area present during rapid carbohydrate accumulation probably constitutes the key to impact of defoliation on a plant. Leaf area available at this critical stage hinges on season, frequency and intensity of use, plant morphology and physiology, temperature, and soil moisture. In essence, the matter revolves around regrowth potential of a plant after defoliation. If leaf area is reduced before accumulation of carbohydrates, and at a time when temperature and/or soil moisture does not permit sufficient regrowth, plant vigor may be severely reduced. The greater the plant's potential to activate meristematic regions and quickly renew leaf area, the greater its resistance to grazing.

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X. RANGELAND MANAGEMENT

A. Range Seeding

Both land stability and forage production, two critical needs in less developed countries, could be improved by range reseeding. Oram (1977) estimated that 100,000 hectares of land revert to desert annually in the Mediterranean regions. Tunisia alone loses approximately 18,000 hectares to desert each year (FAO, 1977). For Iran, Niknam (1970) estimates an annual 100 million metric ton soil loss due to wind and water erosion.

Several factors, including overgrazing and cultivation of non-arable lands, cause desertification. Kernick (1970) reported that throughout the 250 to 350 mm rainfall zone in the Near East and North Africa, huge areas of steppe and mountain vegetation have been plowed up for cereal production and then abandoned. Range seeding could help stabilize many of these areas by decreasing the rate of desertification while providing forage for domestic livestock. Tisdale (1967) reported that seeding and proper management could increase carrying capacity four to ten times in Iran.

Less developed countries in the Near East, Middle East, and North Africa have not adopted extensive revegetation programs. Technical expertise and needed equipment are present, but in limited amounts. Governmental agency implementation may also pose problems. However, the major hurdle blocking successful reseeding programs stems not from a lack of available technology for seed establishment, but from the absence of controlled grazing and follow-through management (Oram, 1977). Stands that have been established are quickly over-grazed and obliterated by livestock. Controlling livestock grazing must be given first priority, otherwise seeding programs will be a waste of resources and time.

When desirable forage plant populations are insufficient to naturally restore rangelands, seeding by artificial means becomes necessary. Seedbeds prepared by methods that destroy all vegetation--plowing--also need to be reseeded. Plummer et al. (1955) estimated that natural revegetation required one desirable bunchgrass plant for every 3 m^2 or one stem of a sod forming grass every 1.4 m^2. Vallentine et al. (1963) reported that one grass plant for each .4 m^2 or 15% ground cover was necessary. In a 225 mm precipitation shrub-

bunchgrass zone, Hyder and Sneva (1956) reported approximately 170 kg/ha of forage was adequate for natural revegetation. Conditions, such as vigor and number of desirable and non-desirable species influence the need for reseeding programs. Thousands of hectares of perennial forages plowed, seeded to cereal crops, and abandoned due to crop failure are frequently colonized by weedy plant species. Many of these areas would be adaptable to reseeding programs.

Site potential and how it fits into an overall management plan need to be considered when selecting areas to seed. The most favorable returns can be expected on sites with high potential and low current production. Abandoned cultivated fields often fall into this category.

Soils with high potential for seeding are deep, fertile, and medium textured (Vallentine, 1971). It is more difficult to obtain a successful stand of seeded forage on sandy or clay soils. Soil 600 mm deep or more also is desirable. As soil characteristics become less desirable, increased rainfall becomes necessary (Rogler, 1960). Several researchers report that seeding success requires a minimum of 280 mm annual precipitation (Cook, 1966; Plummer et al, 1955; Shown et al., 1969). However, some successful seedings have occurred in areas receiving as little as 230 to 260 mm precipitation. Rogler (1960) reported crested wheatgrass (Agropyron cristatum) can be established with 230 mm of precipitation. Site factors such as precipitation distribution, temperature, soil water holding capacity, and aspect affect the amount of available water for plant growth. Together with other environmental factors, these parameters may cause annual average precipitation to be a misleading index for site potential.

1. Species selection

Adaptability to the site and projected uses determine the selection of plant species to be seeded. Primary uses in less developed countries would be stabilization of deteriorating lands and production of forage for livestock. Factors relating species adaptability to a site are: drought tolerance, cold hardiness, soil texture, tolerance to high water tables, tolerance to soil salinity, ease of establishment, aggressiveness, and longevity (Vallentine, 1971). Tolerance to grazing, season of maximum forage quantity and quality, stand maintenance, and types of animals grazing the area also need to be considered.

Numerous plant species are available for seeding and have been successfully established. Vallentine (1971) has constructed a table listing commonly seeded forage plants and evaluates various characteristics related to adaptability on different sites and forage usability. Although a large selection of forage species is available, a few have proven most outstanding. Crested wheatgrasses (Agropyron cristatum and A. desertorum), are commonly seeded throughout the U.S. Pacific Northwest drylands. Introduced from Siberia, these species resist heat, drought, cold, and disease (Konstantinov, 1923). On western ranges receiving 230 mm to 380 mm of precipitation, crested wheatgrass establishes more quickly and easily than most other species providing feed two to three weeks earlier than native forages (Rogler, 1960). Crested wheatgrass is best adapted to

rangelands receiving levels of precipitation 300 mm or less (Vallentine et al., 1963), although it can tolerate 200 mm under certain conditions (Vallentine, 1971).

In dryland regions, formerly cultivated adjacent and intermingling rangelands may possess a high potential for seeding. Sites receiving approximately 380 mm of annual rainfall probably would be suited for intermediate wheatgrass (Agropyron intermedium) or pubescent wheatgrass (Agropyron tricophorum). These two species provide a palatable feed source from late spring through fall, whereas crested heatgrass, resistant to early grazing, supplies feed throughout the spring. Species such as tall wheatgrass (Agropyron elongatum) or basin wildrye (Elymus cinereus), although less palatable, are adapted to saline soils. In more mesic zones (400-700 mm), orchardgrass (Dactylis glomerata), timothy (Phleum pratense), ryegrass (Lolium sp.), and bromes (Bromus sp.) provide a valuable source of forage (Tisdale, 1967). However, many of these sites suffer from extensive erosion and reduced soil moisture holding capacity due to mismanagement.

The advantages and disadvantages of seeding a single species versus a mixture warrants evaluation. Theoretically, a species mixture can more effectively tap a site's resources due to different rooting depths and phenological development. Vallentine (1971) summarized the advantages of seeding a mixture as: homogeneous stand (more evenly established on variable terrain), longer green period, higher yield, higher nutritive value, and adaptability to soil and terrain variability. Seeding a single species, on the other hand, provides more uniform grazing, a more precisely defined forage period and more accurate adaptation to site.

Planting mixtures frequently complicates management problems due to differences in species palatability, drought resistance, grazing resistance, and site adaptability. In 1966, Cook reported that not all species in a mixture could be maintained. Uncontrollable environmental conditions can easily influence the fate of individual species in a mixed seeding. The choice between seeding a mixture or single species primarily depends on site factors and management objectives.

Cover crop, companion crop, or nurse crop (terms used synonymously) refer to seeding an annual crop (usually grain, such as wheat, barley, or rye) jointly with a perennial forage crop. The nurse crop protects young perennial plants from harsh environmental conditions, provides an immediate source of forage, protects against erosion, and decreases the invasion of undesirable weeds. Most studies indicate that nurse crops reduce yields and decrease rates of establishment of perennial species (Stoddart, 1946; Douglas, et al, 1960; Donald, 1963; Wynn-Williams, 1976). Donald (1963) concluded that although production for both perennial and annual species was reduced (despite combined production being greater), depression of associated perennials was generally far greater than the nurse crop value. Stoddart (1946) reported that perennial plants competing with a nurse crop were more vulnerable to drought than perennials seeded alone.

Planting a nurse crop probably would not be advantageous on most range sites. Although combined production exceeds that of a

pure stand during the first few years, grid in [illegible], damage [illegible] ennial plants. In areas highly susceptible to erosion, a nurse crop may help protect pastures that may otherwise lay fallow for the summer.

A somewhat similar technique, preparatory cropping, involves plowing and immediately planting an annual crop during the growing season before perennial forages are planted in the fall. Forages then can be planted directly into harvested crop stubble during the fall without further seedbed preparation. This method helps to limit soil erosion, reduce evaporation, and control weeds.

Vallentine (1971) reports that preparatory cropping generally fails in areas receiving less than 350 mm of precipitation. Stroh and Sundberg (1971) claim that a preparatory crop may suppress seeding success by competing for nitrogen, shading, and lowering soil temperature.

Drilling forage seed directly into an established stand reduces chances of obtaining a successful seeding (Plummer et al, 1955; McGinnies, 1968). Heinrichs and Bolton (1950) reported that crested wheatgrass suffered from direct competition with established species. Established vegetation generally competes vigorously with new seedlings for limited soil moisture.

2. Techniques of planting

Numerous studies have compared fall and spring seeding. In the Northwestern U.S., where the majority of precipitation falls during winter and growth primarily occurs in the spring, fall seeding yields the best results (Houston, 1957; Douglas, et al, 1960; Gates, 1967; Harris, et al, 1972; Klomp and Hull, 1972). Seedlings benefit from a full spring growing period in which to establish. Spring seeding, too, can be satisfactory (Kichler, 1961), but generally not as successful as fall seeding. In cold winter regions, seed should not be drilled until ambient temperatures halt any possibility of fall germination. For Mediterranean climates, seed can be drilled just prior to, or after, the first fall rains since winter temperatures generally are not sufficiently cold to damage seedlings.

A properly prepared seedbed removes weed competition, increases the probability of planting at a desired and uniform depth, and creates a micro climate suitable for seed germination and plant establishment. Vallentine (1971) lists characteristics which create an ideal seedbed: firmed soil below seeding depth, well pulverized mellow top soil, not cloddy or puddled, free from plant competition, free of competitive species, with moderate amounts of plant residue on the soil surface.

Seedbed preparation methods depend upon vegetation present, site erosion potential, salinity, slope, rockiness, soil depth, and soil texture (Vallentine, 1971). Mechanical or chemical methods and controlled burning are most commonly used. Chemical treatment produces a firm seedbed with minimal disturbance to the soil, thus reducing possible erosion. In the U.S. atrazine, paraquat, and dalapon have the capability to remove undesirable grasses such as cheatgrass (*Bromus tectorum*) or Sandberg's bluegrass (*Poa sandbergii*).

Seedbed characteristics obtained with mechanical methods vary with the method and the soils present. Plowing, disking, etc. remove the bulk of vegetative cover from the soil surface, an undesirable condition for erosive soils. Also, certain mechanical treatments applied to loose soils create a fluffy surface layer making proper seed placement difficult and reducing moisture holding capacity. Burning removes nondesirable species and usually leaves a firm, desirable seedbed.

A seed drill distributes seed evenly in the seedbed at a uniform depth. Drilling success relates directly to the quality of seedbed and seed placement. Planting seed too far below or too close to the soil surface delays and reduces emergence (Vallentine, 1971). Disk openers (on drills) can be equipped with depth bands to assure placement of seed at the desired soil depth. Low germination rates due to improper seeding depth are caused frequently by operating the drill at excessive speed. Drill seeding provides for moisture infiltration, wind protection, stand uniformity, and earlier production.

Very few conventional grain drills possess the rugged construction needed to withstand rangeland use. The rangeland drill, however, was built specifically for service on uneven and rocky terrain.

When terrain limits the use of drilling seed can be dispersed by broadcast methods. Broadcast seed germination rates are usually lower (than drilled) due to inadequate soil covering causing a poor environment for seed establishment. Uncovered seeds become targets for rodents and birds, as well as undergoing rapidly fluctuating moisture and temperature conditions (Nelson et al, 1970). Approximately 50 percent more seed is required to cover an area by broadcast compared to drilling (Vallentine, 1971). Hull and Klomp (1967) found that drilling produced seven times more seedlings and reached production sooner than a broadcast stand. Slower establishment rates of a broadcast stand may allow encroachment of less desirable species. Conditions that may provide an acceptable seedbed for broadcasting are naturally loose soils that have been rough plowed or disked.

Seeding rates and row spacing constitute important components to consider when planning range seeding. Unfavorable seedbeds and broadcast seeding impose the need for greater seeding rates. High rates increase the number of plants that emerge; however, if rates are too high, establishment is reduced due to competition between seedlings (Cook, et al., 1967). Hull and Klomp (1967) also reported that higher seeding rates provided better weed control. A general rule indicates a need for approximately 200 pure live seeds per square meter on upland sites, while 270 to 325 pure live seeds per square meter are necessary on bottomland sites. Mueggler and Blaisdell (1955) found crested wheatgrass production was satisfactory at 2.2 to 27 kg of seed per hectare; they suggested 9 kg/ha was adequate.

Distance between rows influences weed invasion and plant palatability, but not yield (Cook et al, 1967). Hyder and Sneva (1963) found yields of wheat grasses were insensitive to rows spaced from 15.4 to 154 cm apart. Conrad (1962) reported that plants in thick stands were more readily eaten, particularly in later stages of maturity. Narrower row spacing (32 cm or less) reduced seedstalk numbers and increased leaf production (Hyder and Sneva, 1963; Cook et

al, 1967).

Newly seeded rangelands require protection from misuse and predators. Improper management of newly seeded rangelands defeats seeding programs. Gates (1967) reported that seeded range should not be utilized for two to five years after planting. Vallentine et al (1963) stated that two full seasons should pass before seeded ranges be grazed. Newly seeded areas also need to be protected from rodents and birds; however these animals more commonly cause damage on small units. Seeding areas 230 ha or more will often prevent concentrations of these animals.

B. Noxious Plant Control

The primary purpose of noxious (undesirable) plant control is to remove the threat of poisonous plants and to decrease the competitive effects of undesirable plants. Eliminating noxious species usually increases forage production and water yields while reducing soil erosion, fire hazards, and livestock losses from toxic plants.

Very little published information concerns manipulation of vegetation on rangelands adjacent to arable lands; most literature deals with shrub steppe areas found beyond cultivated areas. Sites observed in North Africa and the Near East (Winward, 1975; Miller, 1978) indicate vegetation present on range interspersed with cropland primarily consisted of low, thorny, unpalatable shrubs, weedy annuals, and low growing perennials morphologically adapted to grazing, thus producing little forage. Large woody species generally were absent probably due to ecological unsuitability coupled with extensive fuel gathering.

The same principles apply to site selection for initiating a plant control program as for range reseeding. Site characteristics must be taken into account. A control program must be incorporated into an overall management plan or it will fail. Once noxious plants are controlled, desirable vegetation should be established and properly managed.

1. Control methods

Nondesirable plant control methods fall into four basic categories: biological, fire, mechanical, and chemical. The method, or methods, selected relates to the plant species to be controlled, associated plant species present (both desirable and undesirable), topography, soil characteristics, and management objectives.

For rangelands with extremely limited forage production potential, grazing management alone may be the only economically realistic means to stabilize or improve plant populations. This process of control is slow and frequently ineffective where undesirable woody shrubs have become established. In the U.S., primarily in Texas, goats have been used to a limited extent to control undesirable woody species (Magee, 1957). Most commonly goats are used to control resprouting shrubs following fire and mechanical or chemical treatment. At one time goats were utilized in humid valleys of the Northwestern U.S. to clear brush and regrowth from pasture land that had been logged.

However, evidence of goats as a plant control agent in the region's drylands is virtually nil. Goats have been blamed for extensive range damage in some Near Eastern and African nations. Usually the animals have been pastured on already abused, seriously over-grazed range under minimal management. Goats should not be relied on for range reclamation unless intensively managed.

Fire as a tool for removing undesirable plant species is limited in many regions by a lack of fuel. In situations where a fire can be carried across an entire site, the effectiveness of this method would depend primarily upon the morphological characteristics of the target species. Some species with resprouting characteristics are not killed by fire.

Numerous mechanical tools and methods can be utilized to control plants. Aside from tillage, many of these methods are primarily used for removal of small trees or large woody shrubs. Cultivating or tilling rangelands has proven effective for removing low growing shrubs (including those that resprout from the crown), annual weeds, and sod-forming grasses (Cornelius and Talbot, 1955; Rauzi, 1975). Since primary tillage is nonselective and generally destroys nearly all vegetation--undesirable and desirable species alike--reseeding becomes necessary. Therefore, tillage should be used only when the level of remaining residual desirable species is too low to revegetate the area with selective control methods. Also, the plow should be kept off range sites having unstable soils subject to erosion. Range plowing is also limited to relatively rock-free, flat to moderately sloping terrain.

Moldboard, wheatland, and standard disk plows have been used. Whereas these plows are very limited in their rangeland application without risking extensive damage, the rangeland plow--with its independently suspended disks--was designed specifically for uneven rocky sites. Vallentine (1971) reports that rangeland plows can remove up to 90-95 percent of the sagebrush present on a site depending upon rockiness, travel speed, slope degree, and brush size. If the disks are set for a depth of 127-200 mm, plowing will remove shrubs that otherwise would resprout from the crown (Plummer et al, 1955; Cornelius and Talbot, 1955; Robinson and Matthews, 1953). Cornelius and Talbot (1955) concluded that plowing especially when performed in both fall and spring can control annual grasses such as cheatgrass. Sandberg's bluegrass, or other sod forming grasses, also can be controlled by plowing (Evans et al, 1970).

The disadvantages of plowing rangelands are site limitation, soil disturbance, and expense. The rangeland plow, however, can be effective in removing undesirable vegetation (both woody and nonwoody species) if equipment is available and correctly used. The technique applies to sites with little or no remaining desirable vegetation, with soils having minimal erosion potential, and with locales having a high potential for revegetation of desirable forage.

2. Chemical methods

In the U.S.--and the Northwestern region particularly--chemical plant control methods predominate. Sagebrush (*Artemisia* sp.) control by foliar herbicides in this region has significantly increased forage production on numerous sites. Hyder (1953) reported forage

production increased 100-400 percent on sprayed range sites. Cook and Lewis (1963) found crested wheatgrass, intermediate wheatgrass, and tall wheatgrass all increased production in conjunction with a control program. Also, life expectancy of a stand in a control program may extend 15 to 20 years (Sneva, 1972).

Increases in desirable forage production primarily result from increased water availability for plant growth. Roots of both desirable and nondesirable species often seek moisture in the soil zones. Removal of undesirable plants usually significantly increases levels of available moisture, thus increasing forage production.

Herbicides, compared to other plant control practices, are advantageous in terms of selectivity (certain compounds affecting only certain species), use on rough, rocky, or steeply sloping ground, causing minimal soil disturbance, and permitting treatment of more area in a comparable amount of time. However, herbicides do involve significant hazards if misused. Also, equipment required for application can represent significant capital investment.

Compounds in the phenoxy group are the most commonly used herbicides in the U.S. On western U.S. rangelands 2,4-D, 2,4,5-T, and variations of these materials are widely utilized as foliar sprays to control or kill shrub and broadleaved plant species. Along with the phenoxys there are numerous compounds with certain characteristics that make them useful for application on integrated range and cultivated lands. An appendix in the text by Vallentine (1971) lists the properties of herbicides commonly used on rangelands, or proposed for range use.

Designing a spray program, as with any other rangeland treatment, requires thorough evaluation of site potentials and characteristics. Factors influencing herbicide effectiveness include soil moisture, soil characteristics, rainfall, temperature, humidity, light, and wind (Vallentine, 1971). Spray droplets require conditions that permit maximum contact with the target plant species.

Both target and non-target species should be considered when selecting a chemical to apply. Some herbicides are selective while others affect every plant they contact. Physiological, phenological, and morphological plant factors affect herbicide selectivity.

Herbicides can be applied by a variety of equipment ranging from man-carried back-pack applicators, through animal-carried units, tractor or motor vehicle machines, to fixed- or rotary-wing aircraft. Vast areas may be treated most economically by aircraft, provided equipment is available. Back-pack units can be effective for treating isolated, limited area patches of undesirable species.

The objective, target species, physical site conditions, equipment and material available, and economics will dictate rates of application, number of applications, and the use of mixing two or more compounds in one treatment. Higher rates may produce higher percentages of dead plants, but at increased material cost and potentially greater hazard.

The timing of herbicide application influences effectiveness.

Optimal application time is a function of the target plant and herbicide used. Phenoxys exert maximum effect when plants are actively translocating sucrose into meristematic root regions. This generally occurs when leaves and shoots have fully developed, but prior to the thickening of leaf cuticles (Heady, 1975). Phenoxy herbicide effectiveness usually decreases in late spring as soil water decreases and temperatures increase (Hyder, 1954). Time of application is less critical for chemicals that persist in the soil. Chemical fallow has been successfully conducted using atrazine to reduce weed production, eliminate seed germination, and increase soil water (Eckert and Evans, 1967).

The herbicidal susceptibility of adjacent or nearby crops stands is an obvious and critically important consideration, especially when spraying occurs within a mile of cultivated areas. Crops such as cotton, soybeans, fruits, and garden vegetables are highly sensitive to many herbicides. Application should not take place when the ambient temperature approaches 32°C or when wind velocities exceed 16 km/h (Scifres, 1977). Also, less volatile forms of a chemical, such as some of the long chained phenoxys, may be a more desirable choice.

Most herbicides, if used properly, pose no greater hazard than other tools. There is no evidence that herbicides mentioned are transferred in food chains or that they are biologically magnified (Scifres, 1977). In some cases, however, herbicides may increase the palatability or toxicity of poisonous plants (Williams and Kreps, 1970).

Since a thorough literature review revealed relatively sparse information concerning herbicide control of problem plant species in North African, Near and Middle Eastern rangelands, field testing would enable officials to more accurately assess, and more effectively develop chemical control programs. Plots could be established to test a host of variables--from compounds and rates to effect on various plant species under local conditions.

3. Post-control management

Programs that successfully control noxious plant species and allow desirable forages to flourish can be negated by the absence of post control management. Management requires a two step effort ensuring that, after controlling noxious plants, desirable species prosper and strictly controlled grazing follows to avoid over-use and a return to low productivity.

The residual stand of desirable species remaining after noxious plant control should be evaluated to ascertain sufficiency for reestablishment. If the site contains a desirable species stand of at least 10 percent of its normal cover (Heady, 1975), or one desirable plant for every 3 m^2 (Plummer et al, 1955), the species should be able to reestablish itself. If not, the site should be seeded following chemical treatment. Eckert et al (1972) reported that, on a high potential site in fair condition, residual perennial grasses quickly increased yields after spraying. If desirable forages are not quickly established, a site will soon become reinfested with undesirable plants.

Treated sites cannot be expected to provide much forage for the first year or two following control activities. Grazing must be carefully managed to allow either the establishment of newly seeded plants, or seed production and establishment of new seedlings from residual plants. Failure to control and limit grazing will cancel gains achieved through eliminating noxious species.

Chemically based plant control schemes have a high potential for use in numerous developing nations. Past spraying programs meeting with little or no success appear to relate to the absence of grazing management and the failure to integrate vegetation control into a master program of range improvement and management.

C. Range Fertilization

In a review of the literature Schmisseur and Miller (1978) reported the biological and economical outcome of range fertilization is highly inconsistent. Fertilizer, to be effective, requires moisture. Since many range sites lie in arid zones, moisture becomes one of the major factors limiting the use of fertilization.

Fertilizing rangelands in the U.S. to increase forage production is not recommended on sites receiving less than 300 to 370 mm of precipitation (Martin and Berry, 1970; Vallentine, 1971). This condition probably would apply to rangelands in least developed countries as well. Although nitrogen is generally low on moist rangelands, moisture is the greatest limiting factor on the majority of these soils.

The element that apparently has the greatest effect on rangeland forage production, and thus the most commonly used, is nitrogen. Nitrogen fertilizer has been shown to increase production, palatability digestibility, seed production, and seed establishment of forages (Vallentine, 1971). Other elements such as phosphorus and sulfur have induced positive response on lands containing legumes.

Numerous experiments have shown that nitrogen fertilization increases forage production. Cook (1965) reported one application of 27 to 36 kg/ha of N produced 713 to 892 kg/ha additional forage over a three year period. Sneva et al, (1958) found that each kg of nitrogen applied yielded 25 kg of forage, with 22.5 kg/ha being the most efficient rate. On a bluebunch wheatgrass site, 30 percent more forage was produced on fertilized plots.

Fertilization can increase forage quality. Data show that nitrogen fertilizers increase both the crude protein content and digestibility of plants during the growing season (Blaser, 1964; Cook, 1965). However, nitrogen does not increase digestible energy. Application of nitrogen fertilizer increases crude protein levels, but at a time when plant protein content is not critical. For example, crude protein content of bluebunch wheatgrass during the growing season was 14.08, 19.10, and 22.34 percent on plots with 0, 45, and 90 kg/ha of nitrogen (Cook, 1965). Although non-fertilized plots had lower crude protein content, the level was sufficient to support a lactating ruminant animal. At maturity, protein

content in fertilized plants decreased to similar lower levels found in nonfertilized plants.

Fertilization may cause undesirable results. Tests in the U.S. state of Oregon revealed that fertilizing range plants shortened the green-feed period due to an increase in soil moisture depletion (Sneva, et al, 1958). Fertilization has been shown to decrease production of desirable forages. On sites bearing early developing annuals (i.e., cheatgrass), nitrogen fertilization increased these species at the expense of perennial forages such as bluebunch wheatgrass and Idaho fescue (Patterson and Youngman, 1960; Sneva, 1963). Wilson et al, (1966) reported that 90 kg/ha of N applied annually increased cheatgrass 400-600 percent while bluebunch wheatgrass production decreased 50 percent regardless of the initial density of either plant. Kay and Evans (1965) blamed decreases in perennial grass on an early and rapid depletion of soil moisture caused by increases in cheatgrass.

Several observers noted that fertilization does not benefit seed establishment on arid rangelands. Gates (1962), Hull (1963), and Cook (1965) reported that fertilization did not increase seed emergence, survival, or subsequent production.

Increases in forage production frequently realized on range sites are often uneconomical. Fertilization may increase forage production 50 to 100 percent in many areas and still not be economical (Vallentine, 1971). Additionally, the increased production may not be consistent, as shown by Pumphrey and Hart (1973) on dry foothill meadows, native grasses, and forbs. However, fertilization may be justified if used as a tool to increase the efficiency of the overall management unit rather than as a mechanism to simply increase forage production. For example, Cook (1965) reported utilization of forages increased on mountainous areas in the U.S. state of Utah following fertilization. Fertilization also evened pasture grazing due to reduced selectivity (Freyman and Ryswyk, 1969).

D. Range Water Conservation

Water conserving practices such as contour furrowing, terracing, trenching, ripping, pitting or spreading have not been commonly used management practices in the Pacific Northwest. The primary objective of these treatments is to increase water absorption in soils by breaking up impervious layers and/or impeding water runoff. These treatments also reduce sediment removal.

There are numerous studies indicating these practices, if properly implemented, will increase soil water recharge and increase forage production (Barnes et al., 1958; Branson et al., 1962; Wight and Siddoway, 1972; Neff and Wight, 1977). These practices have been more commonly used in the U.S. southwest and Great Plains regions. Success is related to site characteristics such as soil texture and condition. Furrowing in sandy soils did not increase plant production (Vallentine, 1947). Generally, consistent positive responses have occurred on medium textured sites (Branson et al., 1966). Barnes et al. (1958) also reported pitting had little value on rangelands in poor condition.

Terracing and trenching are designed to decrease runoff to non-erosive velocities. However, due to problems of exposing unweathered parent material and piling topsoil, these methods have not proven to be beneficial (Branson et al., 1966). Ripping has also been shown to be of limited value on most sites except on heaving clay soils. Pitting, creating small basins, has increased forage production in the Great Plains on mixed grass stands. However, no response was recorded on pure stands of Agropyron smithii and a negative response was obtained on poor condition sites (Barnes, 1950). Contour furrowing and water spreading have produced positive results more consistently than any of the above methods.

These techniques best fit areas where a large portion of the precipitation runs off the site. In the northwestern U.S., high-intensity rainfall is not as much of a problem as it is in the spring and summer rainfall zones. These techniques should only be used if proper implementation can be guaranteed. In least developed countries these methods of water conservation have probably done far more damage than good.

E. Range Facilities

1. Water developments

Water developments commonly include wells, reservoirs, dugouts, sandtanks, and catchment basins (Vallentine, 1971). Natural water supplies frequently improved for animal use are lakes, ponds, streams, springs, and seeps. Some of these developments, reservoirs, dugouts, sandtanks, and catchment basins, though serving only as temporary watering facilities during the grazing season, often relieve pressure on permanent water sources. Some watering facilities are fairly inexpensive to develop, such as springs, while horizontal and vertical wells cost more. In the absence of an on-site watering source, water may have to be transported to livestock. Bedouin tribesman in Syria transport water by tractor-pulled trailers approximately

PHOTO

Old Roman cisterne used as source of water for livestock in Syria.

eight months out of the year. During the four to five month dry season water is frequently hauled twice a day to supply sheep being milked. In contrast water hauling in the U.S. usually occurs only during emergencies since it is an expensive practice. Another common development on the Syrian Steppe, cistern wells, supply water to livestock during part of the year.

Vallentine (1971) reports the problems most common to livestock watering facilities as too few watering places, inadequate water yield or storage, poorly distributed water sources, and wasteful sources. In many watering facilities seepage and particularly evaporation cause major losses. In some areas water losses may be ten times the amount used by livestock (Waldrip, 1961) dependent upon water surface areas, temperatures, winds, and humidity. Keeping storage facilities covered or water surface areas minimized reduces evaporation.

Water quality can also be a problem. High mineral salt content in water can reduce livestock gains or cause death (Patterson, 1967). Regardless of the salt types, toxic levels occur at about 10,000 ppm. Some water plants, such as blue green algae, may sometimes release a toxin deadly to livestock.

Storage facility size depends on the rate and regularity of water replenishment and the rate of water consumption and loss. Patterson (1967) recommends a storage tank large enough to hold a seven day supply when supplied by an engine driven pump and double that for a wind powered system. Improper construction of reservoirs and other facilities--little or no soil compaction, improperly designed spillways, and steep slopes on retaining structures--lead to breeching and failure with the first heavy runoff.

Inadequate water developments throughout western U.S. rangelands has caused inefficient use of the forage resource. While sites near water become overgrazed, forage on many other sites receives either light usage or none at all. A shortage of water developments in less developed nations also prevails. However, new water developments increase grazing pressure on many underutilized sites and thereby increase the problem of overgrazing and range deterioration. Proper grazing management must accompany water developments.

In the U.S., location and distance between water developments significantly affects domestic livestock distribution. Frequently water is developed solely to improve livestock distribution which encourages proper utilization of unused or overused forages. Since herding primarily influences livestock distribution in many developing countries, water development location will not be as critical in attaining proper animal distribution.

Water quantity and quality help determine the physical practicality of water developments along with characteristics such as site stability (i.e., soil stability, vegetation, etc.). The latter may be more important in countries where large numbers of animals are herded to watering sites. In Tanzania, the Masi commonly herd 3,000 animals to one watering facility daily. Usually extreme range deterioration has occurred around water developments utilized in this manner.

Distances between water sites for cattle should not exceed 400 to 800 m on steep land and 1.6 km on gently rolling terrain; sheep will travel longer distances. Distance between sites could be greater in regions where herding is practiced. Herds frequently travel long distances from water sources since the animals are only watered every other day. Many sites are only accessible during the rainy season due to inadequate water. Drought periods reduce forage production as well as forage availability; where water sources dry up, forage (if present) cannot be utilized. Animals are forced to concentrate on a smaller percentage of rangeland during dry seasons.

2. Other facilities

Fencing, a widespread practice in the U.S., is of little value in many countries due to the constant care of a shepherd, material scarcities, and cost, aside from social conventions antagonistic toward the practice. Livestock are kept off cultivated lands in some regions through the use of cactus or live fences. Demonstration plots necessitate fencing to obtain cultural conditions.

Enclosed areas (corrals) serve at night to protect livestock from predators and thieves. Nomads frequently build corrals out of thorny shrubs. Pastoralists generally return their herds to villages at night.

Providing supplemental salt for livestock, a common rangeland practice in the U.S., appears to be absent in many other countries. The importance of natural salt licks is not known.

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XI. RANGE ANIMALS

A. Ruminants

A major rangeland management objective, consistent with range maintenance, is production of animals. Management in the U.S. may include wild or domestic animals; in North Africa and the Near and Middle East, it is directed to domestic animals almost exclusively. Ruminant livestock constitute the major type of animals used to harvest forage from rangelands.

1. Ruminants defined

A ruminant animal, by definition, is any of a group of four footed, hoofed, even toed, cud-chewing animals which have a stomach with four divisions: the rumen, reticulum, omasum, and abomasum. Forage, after it is eaten and swallowed unchewed, passes into the rumen or reticulum; it is regurgitated later, chewed and mixed with saliva, again swallowed, and then passed through the reticulum and omasum into the abomasum to be acted on by gastric juices.

This digestive system provides a unique function: microorganisms act on food in the rumen chamber, break down fibrous material, and produce organic chemicals which become an energy source for the animal. Ruminants can digest at least 50 percent of most feeds' crude fiber while monogastric animals, such as man, have only a limited ability to digest these coarse plant materials (Maynard and Loosli, 1969).

Ruminant animals include cattle, sheep, goats, water buffalo, bison, deer, giraffes, and antelope. Additionally, camels, llamas, alpacas, etc., are classified as pseudoruminants.

Ruminant animals manifest worldwide importance because of their ability to: digest cellulosic, fibrous, low quality materials; synthesize all essential amino-acids; synthesize all B complex vitamins and vitamin K; and, harvest vegetative material from vast non-cultivated areas. In many countries ruminants also provide draft power, stand as a measure of wealth and prestige, and serve as a tool for managing vegetation to compliment other types of land uses. Ruminant animals not only provide meat, milk, and milk products, but other important items including wool, hair, leather, fuel, pharmaceuticals

(e.g. insulin), special enzymes, and hormones.

2. Worldwide status

Approximately 60 percent of the world's ruminant livestock population resides in developing countries. One estimate places 783 million head in Asia, about 345 million head in Latin America, and 426 million head in Africa, (TAB-AID, 1976). In the U.S. there are about 141 million animals with over 700 million head in other industrialized countries (Hodgson, 1976). The world possesses two ruminant animals for every three people (CAST, 1975).

Ruminants' current importance to the agricultural economy reflects in cash receipts for ruminants and their products in the U.S. in 1972 totalling 43 percent of the receipts for all agricultural commodities (CAST, 1975). Ruminants provide nearly 30 percent of the world protein supply and furnish more than 50 percent of the protein in the American diet. They also provide about one-fourth of the total energy, four-fifths of the calcium, two-thirds of the phosphorous, and significant amounts of other mineral and vitamins needed in the human diet (Byerly, 1973).

Substantial differences exist throughout the world in the manner of raising, utilizing, and regarding ruminants. They generally form part of a subsistence-level system in Asia, consuming very little that farm families might use otherwise. Water buffaloes, cattle, and camels compose an important draft power and transportation resource for the region. In contrast, Latin American countries raise large numbers of cattle, for both meat and milk, on pasture-based systems and on farms ranging from tiny plots to enormous ranches (CAST, 1975).

In Africa, livestock are raised primarily in nomadic systems where both owners and their flocks move from area to area as forage becomes available. Cattle constitute property and accordingly represent degree of wealth, social status, and community influence (CAST, 1975); they are man's legacy to his son. Animals can be exchanged to symbolize formal contracts of friendship and assistance. This strong emphasis on animal numbers taxes forage resources and often reduces the animals' health and quality.

In developed countries, especially the U.S., intensive livestock production attempts to maximize yield through efficient use of grain and feed concentrates. Economic benefits and the U.S. public's demand for high quality meat have led to the practice of feeding grain-heavy concentrates in the last phase of preparing cattle for slaughter.

3. Production

The different values placed on livestock have generated extensive variation in the reproduction and growth rate of animals in various regions of the world. In Africa, the annual cow birth rate averages 45 percent compared with 80 percent in the U.S. (Beck and Sprague, 1975) while calf losses are 35 percent compared to 5 to 10 percent in the U.S. Marketed animals average seven years of age in Africa and the market weight is half the U.S. average. A given gain takes two to three times as much feed compared to the U.S., but Africa's food source is almost entirely forage.

In Colombia, the reproductive rate of cattle is 50 percent and the slaughter weights and daily milk production per cow are considerably lower than in industrialized nations (Raun, 1975). Animal nutrition is listed as the primary constraint with management and animal health as secondary factors. Beef production for Latin America averages 27 kg per head compared to 87 kg per head in the U.S. (Raun, 1975). The productivity of sheep and goats, and total milk production, is even more marked, amounting to a five-fold difference.

When comparing production among developing and developed countries, the different roles animals play under various management systems need to be considered. In most western countries, for example, reproducing cows represent at least 50 percent of the total population. In many less developed countries they frequently represent less than 10 percent since animals often are retained for draft use rather than reproduction and meat (Johnston, 1975).

B. Ruminants' Role in Forage and Cultivated Crop Systems

The production of either annual or perennial forage plants in rotation with cereals or other crops comprises an integral part of farming systems in most countries of the world. Forage provides highly nutritious feed for ruminant livestock in the form of pasture, chopped or cut green plants, grass silage, or hay. Normal per hectare production exceeds demands often permitting stock-piling forages for feeding livestock during dormant or drought periods. This practice helps provide animals a year-round, adequate plane of nutrition for maintaining meat and milk production, sustaining satisfactory reproduction rates, and for supporting animal health by increasing resistance to diseases and parasites.

Livestock enterprises allow use of forage legumes in cropping systems which reduce or, in some cases, largely eliminate the need for nitrogen fertilizers. Well adapted perennial forage legumes can contribute 18-36 kg/ha of nitrogen to the soil annually (TAB-AID, 1976). This soil nitrogen is released through normal decay of roots and nodules, for use in subsequent crop production.

Ruminant livestock enterprises also benefit soil fertility through either direct or indirect application of animal manures. Manures are widely recognized as beneficial to crops when incorporated into the soil. In addition to supplying major nutrient elements (nitrogen, phosphorous, potash, calcium, and magnesium), manures also provide trace elements in an available form (TAB-AID, 1976). Iron, zinc, manganese, copper, boron, and molybdenum, the trace elements, are essential for crop growth; cropped soils commonly have deficiencies of one or more elements. The benefits of manure applications extend through two or more seasons of cropping, involve little or no purchased inputs, and require labor during periods when crop production labor needs are minimal.

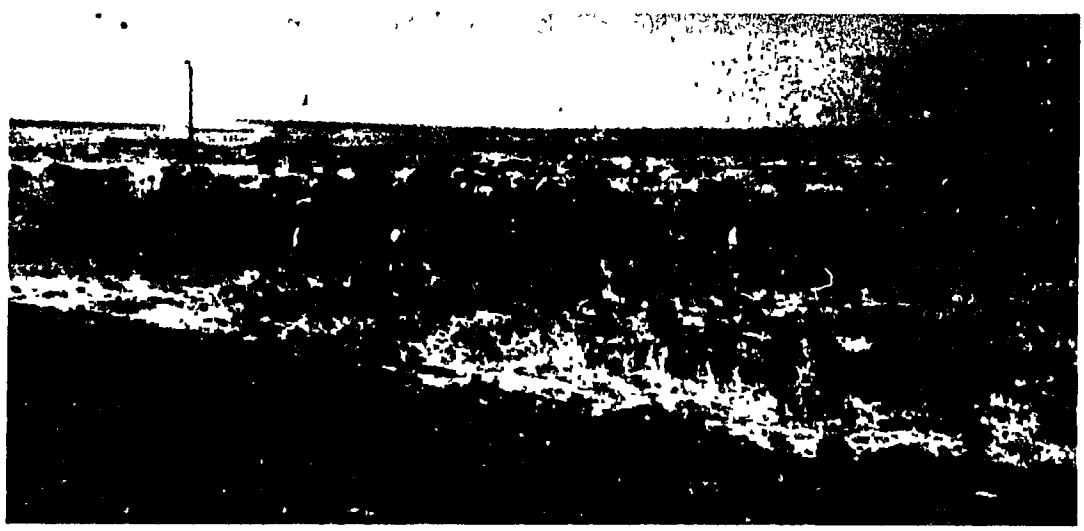
Manure also constitutes an important source of fuel. An estimated 8-12 percent of the world's population depends solely on manure for fuel (Turk, 1975). India uses approximately 60 percent of the manure obtained from cattle and buffalo for fuel, or the

equivalent of 40 million tons of coal annually.

Inclusion of perennial forage grasses in a crop rotation system effectively reduces soil erosion and improves soil structure and permeability (TAB-AID, 1976). The mass of fibrous roots that the forage grasses produce gradually decompose adding a semi-permanent soil humus that makes the soil more mellow and productive.

A rotational sequence of pasture and crop has potential for reducing the abundance of insect pests, nematodes, plant diseases, and certain weeds that could otherwise reduce crop yields. These pests are naturally decimated by the absence of susceptible host plants during periods when forages are grown on the fields.

The ability of livestock to utilize crop residues renders another important contribution in a crop-forage farming operation. Vines, cereal aftermath, and other crop by-products, as well as



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field and roadside weeds, may be used as livestock feed. One study estimated that, on a worldwide basis, there is sufficient residue from grain crops to feed 300 million cattle at the rate of four tons per animal per year if some supplementation is also available (Klopfenstein, 1975).

In addition to on-farm crop residues, locally available by-products from crop processing plants or from distilleries and breweries, as well as fruit and vegetable wastes, and wood-pulp from lumber industries, can be important feedstuffs. Values derived from both the livestock fed, and the animal manures that can be utilized. Without ruminants, these by-products potentially could become pollutants; also, the industries involved would incur disposal costs, which ultimately would be passed on to consumers of their finished products (Hodgson, 1976). Many processing plant by-products presently go unused as livestock feed worldwide, particularly in developing countries. Approaches to efficiently utilizing these by-products have been a recent development in industrialized countries. Expanded utilization of crop residues, especially cereal aftermath, holds exciting potential for many regions.

Draft animals play an important role in some regions. Animal traction expands farming capacity compared to sole reliance on manual

labor (TAB-AID, 1976). Turk (1975) estimates that, despite the spread of mechanical power sources, developing countries depend on animals for well over 90 percent of total agricultural power. Generally, the animal's energy is farm produced avoiding out-of-pocket expenses and reducing the need for fossil fuels and sophisticated mechanization.

Farmers employing systems that include ruminant livestock enterprises also have opportunity to effectively use interspersed lands, areas which may be non-arable due to rough topography, stony or shallow soil, or periodic flooding. Under certain conditions these lands can produce beneficial amounts of forage and thus enlarge a farming enterprise's size.

Food products from plants and from ruminant animals complement each other in their contribution to the human diet (CAST, 1975). A familiar example is the manner in which milk and meat proteins, both high in lysine (an essential amino-acid), improve the biological value of grain proteins which are low in lysine. Similar complementarities arise from the mineral balance achieved from the association of high calcium content milk with low calcium, high phosphorous cereal grains. Animal products also make food mixtures more appetizing for many people, thus helping to achieve a more nutritionally balanced intake (CAST, 1975).

C. Ruminants' Role on Rangelands

Range the largest single category of land both in the U.S. and throughout the world, has few alternatives for contributing food for man other than by providing grazing for animals. The unique capability of the ruminant animal, for not only harvesting the forage resources of these areas but also converting them into a form usable by humans, again should be stressed.

Statistics measuring the contribution rangelands make through animal production vary widely. In the U.S. rangelands contributed 213 million animal unit months of forage in 1970 (U.S.D.A., 1974), or the equivalent of supplying forage requirements all year for 17 million cows, about 40 percent of the beef cow population for that year. Percentage figures for many developing countries would be somewhat higher. Gross receipts for livestock sold from developing areas represent "new" money injected into the local economy which is respent several times within the community expanding economic values far beyond the original amount.

Although rangeland livestock primarily produce food for man, they also may serve as an opening stage or development as they did in parts of the North American West. Ruminant animals have become the backbone of the U.S. rural economy contributing directly to the economic activity in many communities. Processing, distribution, and sale of ruminant livestock products also contribute materially to the non-farm economy of most nations.

In a multiple use setting, as is the case on public rangelands in the U.S., ruminants can be used to alter forage composition,

quality, and availability to favor wildlife (Smith and Doell. 1968; Jensen, et al., 1972; and Anderson and Scherzinger, 1975). Under a proper grazing system they can be used to increase timber growth by reducing competing understory vegetation (Hedrick and Keniston, 1966), and properly managed they can create contrasts in landscape color and pattern that convey a different aesthetic impression than uniform vegetation (Stuth, 1975). In addition, they can be used to help reduce the threat of wildfires by minimizing the amount of fuel present during the dry season (CAST, 1974).

D. Future of Ruminants

Consumer demand for foods of animal origin continues to grow worldwide. Potential demand for increased animal protein exists among 85 percent of the world population (Tracey, 1975). One opinion argues that protein for humans should come from non-animal sources, thereby eliminating the loss in efficiency through conversion by livestock. Possibly the nutritional qualities found in meat or milk could be equaled, or nearly so, by careful assembly of various vegetable products with some fortification (Hodgson, 1976). But providing nutritionally adequate diets solely from vegetable products would be difficult to achieve in many parts of the world and probably would require intensive educational efforts.

As the world population grows and the demand for grain increases, the importance of forage for ruminants will probably increase with less reliance on grain to produce animal foods. In an experiment comparing an all forage feeding regime with an all concentrate ration, satisfactory and approximately equivalent steer carcasses were produced by both systems (Oltjen et al., 1971). However, animals fed the all forage diet had to be fed one month longer than those on the concentrate diet and, overall, were only 86 percent as efficient in converting feed to body weight. The study confirmed that ruminants are capable of shifting from grain to an all forage diet (CAST, 1975). The problems emanate from people--their nutrition, their preferences, their institutions, and their economics (CAST, 1975).

Potential for increasing ruminant production efficiency rests in research to increase forage productivity, to develop forage crops varities with greater yield and digestibility, and to design handling methods that will reduce forage crop losses during harvest and storage (CAST, 1975). Development of new feed sources to extend the unique capability of ruminants to digest cellulosic materials also holds promise. Scientists may be able to develop a mechanized microbial synthesis system to produce edible protein from noncompetitive materials more efficiently than do ruminants, but harvesting and palatability problems will still remain. For mass conversion of forages and other cellulosic materials into palatable, edible food for humans, ruminants appear as the most effective and practical current method (CAST, 1975).

E. Types and Breeds of Range Livestock

An important means of increasing rangeland production hinges on

use of the proper, adapted class or breed of animal. Different animal breeds have unique adaptations to climate, water availability, steepness of terrain, herbage types, disease, parasites, predators, and poisonous plants (Stoddart et al., 1975). Physiologically, sheep and goats are better adapted to desert situations than cattle. The former can withstand temperature extremes with less ill effect and have much lower water requirements than cattle. European cattle breeds are well adapted to cold climates while zebu cattle thrive in hot environments.

Animals that have evolved over many generations under a particular set of environmental conditions usually display ecological adaptation to those conditions; they make efficient use of forage and are tolerant of adverse environmental factors. However, adapted animals may not best suit a market nor best satisfy the consumer's demand for red meat (Stoddart et al., 1975). Consequently, selection of animals with specific ecological and physiological characteristics must be conditional to consumer demand for those types of animals. Selective breeding programs have played a significant role in integrating these factors, especially in the developed countries.

1. Sheep

Approximately 1.5 billion sheep and goats of the world represent the major single commercial source of animal fiber (Winrock International Center 1976). Though relatively small, their carcasses and daily milk yields make an exceedingly important contribution to the nutrition of people in developing countries where food preservation technology is still primitive. Sheep and goats fit small land holder economies more readily than any other class of livestock.

Iran contains more than 20 breeds of sheep (Jones, 1956) with the Baluchi, Makov, Karakul, Afshari, and Awassi breeds most prevalent.

PHOTO

Awassi (fat-tail) sheep in the Mideast.

Nineteen of the breeds classify as fat-tails, a group highly adapted to local conditions and management practices in many developing countries. Their wool is generally coarse and used for making carpets and oriental rugs. Some attempts have been made to cross fat-tails with Rambouillets to obtain a fine wool for the clothing industry.

Most of the sheep in Turkey also belong to the fat-tailed, carpetwool breeds. They include the White Karaman in Central Anatolia, the Red Karaman further east, and the Dagli breed in the western regions (Mason, 1967). Merinos have been imported for some years and used to upgrade the fat-tails in some portions of the country.

The majority of sheep in Syria belong to the Awassi breed; in Lebanon and Israel the Awassi and Karaman breeds predominate. Israel has devoted extensive effort to developing crossbreeds using selections of the Romney, Dorset Horn, and Suffolk breeds from Europe, the Columbia from the U.S., the Rambouillet from Canada, and the Border Leicester from Australia.

In Tunisia and Morocco, major sheep breeds include the Barbary and Berber breeds, respectively. These two countries have initiated improvement programs through crossbreeding using Merinos and some French breeds.

Common breeds in developed countries include the Merino, Rambouillet, Suffolk, Hampshire, Columbia, Lincoln, Southdown, and others. Sheep numbers in the U.S. have steadily declined for the past several decades until a recent increased demand for lamb and a renewed interest in woolen articles tended to stabilize the industry. Lack of qualified herders and continued predator-caused losses provoked a movement from rangelands to more intensified pasture management systems.

Crossbreeding, a well-accepted practice in developed countries, has generated improvements in weight gain efficiency, multiple births, disease resistance, and tolerance to specific environmental conditions. Crossbreeding could be used to increase production efficiency in developing countries flocks, too, but small farmers generally cannot afford to invest resources in selection programs; presumably governments will have to provide the economic and technological assistance for breeding improvement programs. Some crossbreeding work in the past has led to a decline in animal productivity due to reduced hardiness of the progeny to local environments. Breeding programs, in order to be effective, must be closely linked with improved management.

Sheep disease problems in developing countries also have been the focus of research. Allonby (1976) estimates that, on a worldwide basis, there are some 300-400 diseases that ultimately effect sheep production. Vaccinations, used for a while in developed countries, now are being introduced for reduction of such diseases as entrotoximia and blackleg. Many technologies and medicines developed in industrialized nations have application worldwide. Demonstration programs need to be expanded to include all segments of animal production programs. An adequate, year-round nutrition plane could be a major step toward reducing losses from livestock diseases.

Fat-tailed docking (removal) and castration of males have proven

to be beneficial, but socially unacceptable in some regions. Traditionally the fat-tail has been a part of the staple human diet; also, reserves in the tail help sustain animals through dry seasons. Experiments have shown that the tail is unnecessary where adequate forage is available, and also that conversion to meat may be greater without it (Smith, 1976). Current tradition and lack of forage in the dry season generally results in lambs being left undocked.

People in certain regions traditionally slaughter and eat only male sheep, unless a female is sick or has reached an age of lowered productivity. Males in the market are identified by the testicles left hanging on the carcass. To reduce the effects of this traditional concept research has shown that short-sack castration--placing an elastic on the scrotum, but leaving the testicle up in the abdominal cavity--accomplishes the benefits of castration (controlled breeding and increased growth rate), yet still leaves the testicles visible for the market (Smith, 1976).

Confining sheep in enclosed barns or sheds during the winter presents another production problem. Many sheep owners feel that their animals cannot tolerate cold temperatures, but in so doing leave the animals to breathe stale air and wallow in wet sheds. Experiments by Smith (1976) indicate that animals in sheds with open windows and doors experience reduced rates of pneumonia and parasites. The concept is not yet widely accepted in developing countries.

2. Goats

The domestic goat, a hardy animal especially adapted to arid and semi-arid regions, is widely distributed throughout the inhabited parts of the world. Goats are kept for their meat, milk, skins, and hair; in some areas they are used as control agents for unwanted shrubby or weedy vegetation. Although the production from many goat populations is relatively small, the animal forms an important component of agricultural systems in developing countries because of physiological and biological adaptability to low nutrition and management levels. Goats especially adapt to small farm subsistence situations.

In Iran and surrounding countries, common goat breeds include the Kirgiz, Mongolian, Tibetan, and Don (French, 1970). Black or mixed colors are more common than white. Goats of the Near East include the Angora, Maltese, and Red Damascus. Africa is known for its Nubians, but many goats have not been adequately described and differentiated in that continent (French, 1970).

Goats have been both praised and condemned for their adaptiveness to severe foraging conditions. Because they can utilize nearly all types of vegetation, they have been used to reduce unwanted shrubs and weeds from range and cultivated lands. These normally would be unused by sheep and cattle. On the other hand, their non-selectivity has potential to further deplete range conditions and cause serious erosion problems. Iran and Tunisia have placed strict bans on goats in certain areas. The key to whether goats are beneficial or destructive users of range and croplands depends on how they are managed. In the absence of managerial capability and incentive and under pressure of increasing livestock numbers, it is not likely that they will always be used in a non-destructive fashion.

Goats in the U.S. play a relatively minor roll in livestock production and represent less than .003 percent of the world's goat population (FAO, 1974). Though occasionally used in the Southwest region to control unwanted brush, their overall role is mainly restricted to milk production at the individual family level.

3. Cattle

The world contains somewhat over one billion head of cattle (FAO, 1970). Asia contains 40 percent of the world herd; animals are kept principally for draft purposes, but may be milked as well (Rouse, 1970). Ten percent of this total exist in Africa where, except in South Africa, they contribute little other than milk. The remaining 50 percent inhabit Europe, the western hemisphere, Australia, and New Zealand, where they are grown for beef, milk, or both.

In many developing countries cattle are especially valued for other than monetary returns. They become evidence of wealth and prestige and are eaten only at ceremonial functions or when they die naturally. In these regions cattle are usually of the zebu breeds, often referred to as "local purebreds." Individuals are small, with mature cows averaging only 227 to 318 kg, but ideally suited to the fluctuating forage, water, and temperature conditions that prevail.

British cattle breeds dominate most range operations in the developed countries with Hereford, Angus, and Shorthorn the major beef breeds. Recently, Charolais, Brown Swiss, Freisan, and Simmental have become important (Rouse, 1970). Extensive research conducted on breeding, nutrition, and physiology has led to increased animal efficiency and production that can be applied to cattle production in developing countries, especially where a complete packaged program can be implemented.

Nutrition stands as a major factor limiting animal production in developing countries. Very little effort is devoted to storing feed for use by animals during dry seasons. Since cattle are less adapted to scavenging for forage than sheep, goats, or camels, significant production losses occur due to inadequate year-round nutrition and subsequent nutritionally related diseases.

Various levels of genetic improvement programs are underway in most countries. Purebred Brown Swiss cattle are being raised under government controlled programs both for demonstration and to supply small farmers with genetic stock for improving their own herds. Although the crossing programs have been successful, especially for improved pasture or cropland areas, little genetic improvement has been implemented at the village level.

F. Animal Nutrition

The extremely important aspect of range animal nutrition ranks as a factor limiting livestock production from many rangelands. Animal nutrient requirements include: minerals for bone building, cellular formation, body fluids pH regulation, and enzyme regulation;

vitamins, which play a multiple role in the body processes; protein to build and repair animal tissue; and fats and carbohydrates for the production of energy (Stoddart, et al., 1975).

1. Minerals, vitamins, and proteins

Minerals most likely to be deficient on range and pasture lands include: phosphorus, calcium, iron, copper, cobalt, sodium, chlorine, iodine, potassium, and magnesium. From the standpoint of amounts present in animals, calcium and phosphorus stand as the most important by far constituting over 70 percent of the body ash (Maynard and Loosli, 1969). These two minerals are essential for bone growth and numerous other body functions.

Cobalt, iron, and copper deficiencies occur in forage from widely distributed areas of the world. Additionally, improper balances of several minerals, such as calcium, magnesium, potassium, and sodium, are believed to cause such sickness as grass tetany, milk fever, and wheat poisoning (Stoddart et al., 1975).

Vitamins A and D appear to be the only vitamins of major importance to herbivorous animals (Hart and Guilbert, 1933). Since vitamin D derives from sunlight, it is unlikely to be deficient under range conditions. Vitamin A, formed from carotene found in fresh green feed, serves several important functions in the animal. Deficiencies usually arise when animals graze on dry feed. Some vitamin A can be stored in the liver; therefore, a deficiency may not become evident for 60 to 180 days after range feed begins to dry up (Stoddart et al., 1975).

Growth, weight gain, appetite, milk secretion, and regular oestrus rely on protein intake (Halls, 1970). Daily protein requirements increase with age and size, at least during early growth. Livestock feeding standards generally indicate that 0.27 kg of digestible protein per 45 kg of body weight suffices for cattle and sheep. If protein, the most important nutrient to the animal, becomes seriously deficient, the body may fail to maintain itself. Even a slight deficiency adversely affects reproduction, lactation, growth, and fattening processes (Morrison, 1957).

2. Fats and carbohydrates

Ruminants genenerally do not depend on fat in the diet, because fatty acids can be synthesized in the rumen from carbohydrates and proteins (Dietz, 1970). Dietary fat does, however, provide the most economical source of energy; thus, a deficiency causes the body to use a less efficient source of energy. Carbohydrates, including sugars, starch, cellulose, gums, and related substances, constitute three-fourths of plant material dry weight (Dietz, 1970). The bulk of plant material range animals consume consists of some form of carbohydrate. Micro-organisms in the rumen reduce the carbohydrate constituents producing volatile fatty acids that provide most of the animal's required energy.

3. Forage nutrition

Spring and summer ranges possess comparatively higher forage than fall and winter ranges, the latter commonly being nutritionally

deficient. During fall and winter animals should receive nutrients at a level to meet gestation requirements. Animals undergoing early lactation on spring ranges require a 25 to 30 percent higher nutrient level than animals in gestation (Cook and Harris, 1968).

Browse (shrubby) plants on winter ranges meet the recommended standards for protein, in most cases, and offer exceptionally high carotene levels. They are, however, slightly deficient in phosphorus, and decidedly low in energy-furnishing constituents (Cook and Harris, 1968). During winter, grasses exhibit marked protein, phosphorus, and carotene deficiencies while providing useful sources of energy. Therefore, a dietary mixture of browse and grass more nearly meets a gestating animal's nutritional requirements than either forage class alone. Forbs, generally intermediate to browse and grass in nutritive content on spring and summer ranges, become dried and unavailable on fall and winter ranges. Animal preference for certain classes of forage, therefore, remains an important factor affecting the diet's nutrient content.

Both sheep and cattle generally alter their dietary preference as the season progresses. Preference for grass by both animal classes decreases, while the choice of browse increases (Cook and Harris, 1968). Cattle preference for forbs increases during the early season and remains intermediate to grass and browse the remainder of the season. Preference for forbs by sheep remains high during the entire season.

4. Supplements

Seasonal supplementation of the range diet may be necessary to meet livestock nutritional requirements. However, since rangeland grazing is generally an extensive livestock operation based on low-cost feed, supplemental feeding essentially reduces to an economic question of balancing costs against additional production (Stoddart et al., 1975; Cook and Harris, 1968). Supplemental feeding is economical only in special circumstances involving minor portions of the total animal diet (Shepard and Hughes, 1968). Aside from emergency periods requiring substitute feeds, these special circumstances include protein and mineral imbalances that prevent animals from effectively using digestible nutrients.

Common protein supplements include grain, cottonseed, and soybean products. These concentrates generally contain from 33 to 43 percent digestible protein (Shepard and Hughes, 1968). Consequently, relatively small amounts will satisfy the daily requirements of common classes of livestock (NAS-NRC, 1963, 1964).

Pelleted protein supplement with 25 percent of its nitrogen as urea also may be used. Rumen bacteria can convert urea and other nitrogenous compounds into proteins for the animal. Approximately one-third of the total protein requirements may be met in this way under suitable conditions (NAS-NRC, 1963).

In general, protein supplementation is profitable when it increases the reproduction rate of breeding herds, reduces death losses, and permits replacement of costlier sources of feed or forage on the range--especially in winter (Shepard and Hughes, 1968).

The more common mineral supplements include calcium, phosphorus, and salt (NaCl). Calcium and phosphorus usually are offered in the form of dicalcium phosphate (Stoddart et al, 1975). Iodine often is provided in the form of iodized salt. Other minerals such as iron, copper, and cobalt may be deficient on a local level.

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XII. GRAZING MANAGEMENT

The most critical rangeland problem in developing countries is the lack of grazing management. Attempts to improve range condition through brush control, reseeding, water developments, and other practices will be futile without attaining control of the grazing animal. Williams et al (1968) stated, "overgrazing is the single greatest cause of range deterioration in all parts of the world."

In Iran, Shaidaee (1974) estimated that approximately 20 million hectares would respond to reduced stocking coupled with better range and grazing management. Destructive grazing practices occurred primarily through excessive animal numbers, grazing too early in the spring, and grazing for an overly long period. In 1966, after Tisdale visited ten countries in Southwest Asia, East and North Africa, and the Eastern Mediterranean, he observed that "range improvements have little value with present livestock numbers," (Tisdale, 1967).

Societal structure, inadequate operator understanding, lack of trained technicians, enforcement difficulties, and the absence of regulatory policies constitute a problem complex that discourages grazing management. Many rangelands are open for grazing on a first come, first served basis similar to rangelands in North America in the 1800's. Additional problems in grazing management arise on intermingled range and cultivated lands. Both the shepherd and the cultivator act as separate entities, making independent decisions that may or may not be compatible with one another (Whyle, 1956).

A. Grazing Systems

Grazing systems, an important element of grazing management, defines systematic recurring periods of grazing and deferment for two or more pastures or management units (Society for Range Management, 1974). Systematic grazing as a method for range improvement was first proposed in the U.S. by J.G. Smith in 1895. During and prior to this period, livestock on U.S. rangelands were allowed to consume forage when and where they pleased (Frandsen, 1955). If some forage was left behind by one cattleman's herd, another operator would follow and allow his herd to graze the same area. This system was not applicable to any kind of deferment or range readiness. This is the

present state of grazing management in many least developed countries.

Continuous, deferred, rested, and rotation are four terms commonly used to describe grazing systems. As defined by Heady (1975), "continuous grazing is unrestricted livestock grazing through the whole grazing season; deferred specifies that a pasture is not grazed until seed maturity is assured or a comparable growth stage has been reached, and that it is grazed after seed maturity; rested stipulates that a pasture is not grazed at all in a given year, not even the mature forage is harvested; and rotation grazing is when animals are moved from one pasture to another on a scheduled basis."

Continuous grazing, which may be either season-long or year-long depending upon the climate, is considered to be the simplest grazing system to manage. This system generally requires fewer developmental inputs, less labor, and minimal disturbance of animals. Animal gains are usually rapid due to ample opportunity for selectivity when high quality forage is available. Lower density of animals grazing a management unit during a plant's most vulnerable growth period creates another advantage for this system. Although key plant species in a continuous pasture are susceptible to grazing each year during their critical growth period, livestock may consume relatively small quantities of these plants during this period. For instance, Smith (1967) reported that Idaho fescue, a key management species, was not utilized by livestock until mid-August on a season-long grazing system. Spreading forage use over the entire grazing season tends to reduce consumption of important plant species during critical growth periods.

Problems that may arise in continuous grazing concern the chance that a greater selective pressure may be imposed on key forage plants, the lack of a definite rest period for plants, and the difficulty of maintaining proper use over the entire pasture. The latter, even use over a pasture, would not be a problem where herding is practiced. The critical concern of a continuous system under herding would be animals consuming the more desirable forage species, and the intensity of use during the growing season.

Deferred grazing helps increase plant vigor by allowing plants to complete physiological processes such as carbohydrate accumulation and reproduction before grazing reduces leaf area. Newly seeded pastures are frequently deferred until plants become established. However, this method most commonly applies to a rotation system between two (or more) pastures with each grazed and deferred in alternate years.

As compared to continuous grazing this system requires greater economic input. Also, animal selectivity is reduced, and a higher concentration of animals utilize non-deferred pastures during plants' active growth stage. However, the higher animal density may reduce selective grazing pressure on key forage species.

Rotation grazing generally relates to irrigated pastures or subhumid range. This system strives to concentrate animals on a small pasture area to achieve relatively uniform utilization of all plants. Since animals are moved from pasture to pasture on a scheduled basis,

plants receive periodic rest. Although rest periods generally do not correlate with growth stage, conditions usually favor regrowth since water is not as limiting.

Extensive economic inputs (water, fencing, labor, etc.) and a high density of animals utilizing a pasture during active plant growth define undesirable features of the system. Rotation grazing is usually limited to productive pastures due to economics. High intensity grazing for short periods may be accomplished on rangelands devoid of fencing with animals moved by herding. However, regrowth potential on limited moisture range sites would be short lived leading to problems with plant vigor.

Rest rotation, a popular grazing system with one U.S. government agency, was developed by Hormay (1970). In a five-pasture system, over a five year period, each pasture would be fully grazed in year one, completely rested in year two, deferred in year three, rested the next year, and grazed during flowering and senescence in year five. The system was designed to fully rest a pasture following season-long grazing. Deferment during the third year allows seeds to fully mature and then be trampled into the ground by livestock. In year four, resting the pasture encourages seedling establishment. Grazing during the fifth year is delayed until flowering. The cycle repeats each five year period. The same system also has been used for three or four pasture units.

Among its disadvantages and problems, rest rotation grazing harvests approximately half the available forage, and utilizes only 40 percent of the management unit (Heady, 1975). Also, forage utilized on two of the three pastures being grazed is low quality. From the vegetation standpoint this system tends to encourage wolf* plants. Further, the two years managed for seed production and seedling establishment may not coincide with favorable weather conditions. This also holds true for the year of rest following season-long use. The entire herd concentrates on 20 percent of the management unit during vegetative growth. In the remainder of the year, part of the herd remains on this pasture.

Numerous variants of the four grazing systems mentioned can be found in the western U.S. Other systems include the best pasture system (Herbel and Nelson, 1969), one crop-two crop system (Hyder and Sneva, 1963), Merrill's four pasture system (Merrill, 1954), and the Acocks-Howell plan (Acocks, 1966).

Heady (1961) and Herbel (1971) summarized results reported by various researchers throughout the western U.S. to compare the effectiveness of various grazing systems. Although the results were highly variable, both authors concluded that grazing schemes revealed no advantage over continuous grazing in livestock production. Vegetative response usually was comparable and animal gains either were equivalent, or greater with continuous grazing.

Attempting to compare the efficiencies of various systems presents problems. Varying weather conditions, additional range

*wolf plant: a plant normally palatable, that is not grazed due to the presence of coarse fibrous materials.

improvements, differing managerial techniques, and environmental variation, complicate the task. Weather conditions can cause greater year to year changes in vegetation than any particular grazing system can. Also, comparisons of systems operating on well managed rangeland may evidence relatively small vegetation changes. Range developments necessary for implementing a system--such as fencing and watering--often are not properly credited for observed differences between systems. Although numerous studies have been performed, comparing grazing systems presents complexities due to numerous variables.

Most systems, excluding the basic method of continuous grazing, were developed to eliminate grazing during some critical growth stage of key forage species and thereby benefit the plant. Many systems concentrate animals on part of the management unit during a specified period or periods to more evenly utilize available forage. Two important questions remain unanswered when evaluating a system: does intensive grazing of forage plants during their active growth stage for one year (out of two or three, depending on the system) cause more damage than can be repaired by the following years of rest or deferrment; and, is range improvement due to the system or management?

A successful grazing system rests on the important concepts of flexibility and wise management. Grazing systems have not caused overgrazing and degradation of rangelands; inept management has. A grazing plan must be flexible to best fit varying environmental conditions. While the principles of various grazing systems should be considered for developing regions, the major problem and first point of attack remains, lack of poor management.

In many developing countries animal movements relate primarily to forage availability rather than plant growth requirements. On Syrian rangelands, nomads push their animals into the steppe as soon

PHOTO

Nomadic herd on the Syrian steppe.

as green feed becomes available in early spring. This forage quickly diminishes in summer; some herdsmen push deeper into the steppe while many others turn their animals towards cultivated land to graze on crop residues and weeds growing on fallowed land. Crop residues, an

important forage commodity in many regions, usually support livestock until late fall, or early winter. Throughout the winter months,

PHOTO

Goats and fat-tail sheep jointly grazing crop residue.

many illagers and nomadic tribes must feed their animals expensive supplements (i.e., cottonseed cake, etc.). This grazing cycle is similar for the villagers which tend to also depend on vegetable crops. However, rangelands grazed by their animals in the spring exist on patches of shallow soil intermingled with cultivated lands.

B. Stocking Rate

The term stocking rate defines the number of animals grazing a pasture during a specified period of time. An ideal stocking rate would be the number of animals on a pasture that produces the greatest return without damaging the resource. Animal return should be evaluated as kilograms of animal products produced per hectare rather than simply animal numbers per unit area. Although stocking rates relate to grazing intensity, even a properly (or understocked) range improperly managed may display severely overgrazed areas. Stocking rates that lead to overgrazing exist as a critical problem for many developing regions. Some observers estimate ranges to be overstocked by two to twelve times their grazing capacity (Tisdale, 1967).

1. Grazing capacity

The proper stocking rate for a management unit relates to its grazing capacity. Heady (1975) defines grazing capacity (also known as carrying capacity) as, "the number of animals that produces the greatest return without damage to the physical resources and in concert with other values received from the land." Quality and/or quantity of forage most often establishes carrying capacity limits.

Variables that affect grazing capacity include types and class of animals, season of use, grazing distribution, site condition,

site potential, and other land uses. Various types of domestic livestock exhibit unique forage preferences and foraging habits. The character of one range unit may best suit a particular type of livestock, but not another. However, higher returns on animal products per unit area may be achieved by grazing more than one type of livestock (Cook, 1954). The class or age of animal, within a type, also may influence foraging ability. For example, young cattle (heifers or steers) utilize pastures more efficiently than lactating cows (Young et al, 1967). Also, food requirements vary between classes of animals. Fewer lactating cows than non-lactating cows can be grazed on a pasture where forage quality is the limiting factor.

Season of use affects forage quality and quantity and determines a plant's sensitivity to grazing. If even animal distribution cannot be attained, pasture carrying capacity would be lower than the level reflected by forage production. Site condition also influences proper stocking rates. Hyder (1953) reported that 50 percent utilization, generally considered moderate, probably would be excessive for rangeland comprised by a large proportion of area in mediocre condition. Other land uses may conflict with, or be complimentary to. grazing. Carrying capacity may increase, decrease, or be unaffected by other land uses depending on the type of use and the land.

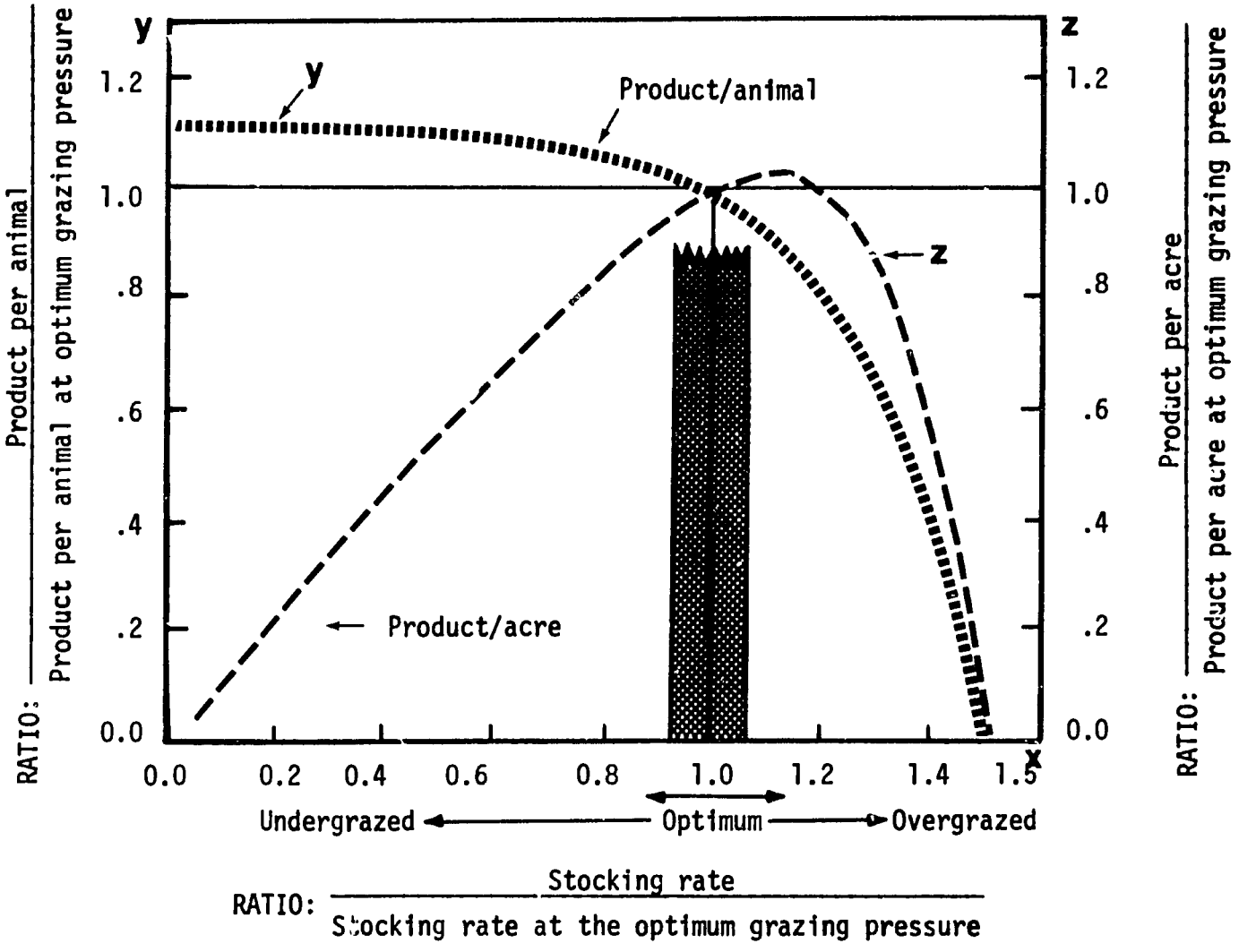
2. Optimal rate

Range resources need to be inventoried to determine proper stocking rates. Knowing the extent and nature of the resource provides a basis for calculating the optimal stocking rate. When range is understocked (fewer animals than the optimum rate) animal performance relates to the potential of the breed (Morely and Spedding, 1968). Understocking causes forage to mature, become less palatable, and thus decrease the carrying capacity (Cowlishaw, 1969), or, in rare cases, reduce gain per animal. High stocking rates or overstocking often precipitate a rapid decrease in animal gains (Mott, 1960). Overstocking generally leads to less selectivity by animals, less high quality forage available, changes in vegetative composition, increased soil erosion, and reduced water penetration into the soil. Mott (1960) reported that an optimal stocking rate occurs at the point where product per animal and product per hectare, as indicated in Figure 16, intersect. Stocking at rates falling to the left of the intersect allows more flexibility in herd management. The optimal stocking rate embodies a range of values rather than a single figure.

Weather fluctuations cause forage production variation and thereby exert a dominant influence on stocking rate. During dry years, either alternate forage sources must be secured or the animal population reduced. In cases where little forage is stored and alternative sources are nil, animals are at the mercy of the climate. Intensive management requires yearly adjustments to fit varying forage supplies. Heady (1975) believes that, to maintain sufficient cattle herd size flexibility, the base herd (breeding cows) should account for 80 percent of the average grazing capacity. For regions with frequent drought years, the base herd should comprise 55 to 60 percent of the herd; the remainder, in the case of cattle, can be young heifers to serve as replacements. Carrying capacity must be estimated several months in advance under dry rangeland conditions since forage will need to be available following the growing season.

Figure 16 - STOCKING RATE

Relationship of product per animal and product per acre to stocking rate.



The performance of both forage and livestock should be observed after establishing the stocking rate. Often when animals start to lose weight or become less productive due to overstocking, vegetation is already in a state of retrogression. Estimation of available forage in a pasture should be based on stubble remaining after grazing rather than the amount removed. A "rule of thumb" states that 7.6 to 12.7 cm of stubble should remain with approximately 50 to 55 percent of the plant harvested (Crafts, 1937; Pickford and Reid, 1942, 1948; Reid and Pickford, 1946). However, these values will vary with environmental conditions, vigor of the plants, plant species, season of use, and management.

C. Animal Distribution

Attaining even distribution across a pasture often constitutes one of the greatest challenges of grazing management in the western U.S. Optimal livestock distribution produces even forage use throug out the range management unit (Heady, 1975). Uneven distribution reduces carrying capacity.

Animal distribution in the U.S. is controlled by fencing, watering, salting, riding, herding, trails, vegetation manipulation, burning, and fertilizing. Class of animal also affects distribution studies have shown differences between young and mature cattle. Hickey and Garcia (1984) reported young cattle utilized variable terrain more uniformly than more mature animals or mixed classes of cattle. However, they found yearling heifers were more active than yearling steers on steep rocky terrain.

Cook (1966) noted 21 variables associated with cattle distribution on mountainous terrain and cited percent slope, distance from water, thickness of brush, and percent of palatable species as most important. Watering points, a major influence on animal distribution, often become the focal point of grazing pressure. One study indicated that cattle consumed approximately 100 percent of the bunchgrasses near water, 78 percent 180 meters away, and 32 percent 900 meters away. Distances between watering points should not be greater than 6.4 kilometers in flat country and 3.2 kilometers in rough terrain for cattle (Barnes, 1914, in Heady 1975). Stoddart, et al (1975) report an ideal distance of 1 kilometer in rough country. If sheep are being watered once a day, the same distances would apply, and if watered less frequently, distances could be increased. Mueggler (1965) reported that the steeper and longer the slope, the lighter the forage use is upslope.

In regions where the majority of people herd their animals, animal distribution becomes more a function of the herdsman than

PHOTO

Herding sheep on the Syrian steppe, an example of animal distribution.

the animal. However, the problem of overuse around watering facilities exists, often to an even greater extent.

D. Crop Residues

Klopfenstein (1975) reported that if .5 kg of collectible crop residue was produced for every .5 kg of grain approximately 1.25 billion tons would be available on a worldwide basis and that this resource could support approximately 300 million cattle.

The term crop residue or crop aftermath includes all parts of the crop plant left in the field after harvest plus any grain passed over, dropped, or not harvested. Crop residue also can refer to crop plant matter that has been processed (sugarbeet pulp, sugarcane bagasse). For dryland range-cereal regions, crop residue usually occurs as cereal straw, leaves, and chaff (plant material surrounding the grain kernel).

1. Using crop residues

Cereal crop aftermath serves as an important forage resource in many developing regions. Grazing stubble during the fall and winter after wheat harvest provides a major source of roughage for sheep in North Africa, the Near East, and the Middle East. In Turkey, stubble and straw are estimated to comprise one-third of the crop's value. In Pakistan the price ratio of grain to straw is frequently two to one. Forage shortages cause cereal residues to be proportionately worth more as a livestock feed than in more developed countries.

In the U.S. Pacific Northwest region, cattle are the primary consumers of cereal aftermath. Some cases of sheep using this forage resource have been reported, but the practice is not common due to relatively few sheep in this wheat growing area. Some of the region's wheat farmers feed their own cattle, while others lease their lands for US $2.50 to $5.00 per animal unit month (Cook, 1977).

Livestock in many developing regions feed on cereal residues directly in the fields. Many cultures sanction open grazing by anyone on fields that have yet to be planted, or that have been harvested. In some countries, such as Syria, stubble fields are leased to nomads. In some instances chaff was stockpiled inside villages for livestock use.

The same two approaches, consumption of crop residues in the field or consumption of stockpiled reserves, are employed in the U.S. The former is the cheapest method. However, Klopfenstein (1975) estimates that this technique wastes approximately 70 percent of the residue that could be harvested.

Due to the absence of fencing, many livestock operators erect a single strand of electrified wire to control cattle grazing. When the animals are removed, the wire is re-rolled for reuse in the future.

Timing for feeding crop residue in the U.S. varies with the ranching operation. Generally, animals are moved into harvested

fields in fall and remain there through early spring.

Collection of chaff for storage in field dumps is accomplished by a specially constructed wagon pulled directly behind a combine harvester. The chaff, emerging from the back of the combine, accumulates in the wagon which is spring loaded to automatically dump its contents when full. Many of the operators will mix chaff with alfalfa hay at about one part chaff to two parts alfalfa. The practicality of this procedure would depend on the benefit-cost ratio a well as weather that might limit livestock from using open fields during the winter. Due to the bulky nature of most cereal residues hauling them long distances is usually not economical.

A question raised by many wheat growers, and as yet unanswered concerns the impact grazing animals have on future wheat crops planted in grazed fields.

2. Residue quality

Crop aftermath is known to be a poor quality forage being deficient in crude protein, vitamin A, phosphorus, and possibly other

PHOTO

Cattle grazing cereal aftermath in Northwestern U.S.A.

necessary nutrients (Boawn and Allmaras, 1974). Additionally, residues may contain over 90 percent dry matter (Anderson, 1976). Swan and Lamming (1970) report a decrease in digestibility of the total diet as the proportion of straw increases.

The daily crude protein requirements for cattle range from 5.9 percent of the total diet for dry, pregnant cows to 9.2 percent for lactating cows, as suggested by NRC (1970). Wheat and barley straw contain between 1 and 3 percent crude protein with the chaff ranging from 2 to 5 percent, dry weight basis (Anderson, 1976). Since cereal residues are low in protein, cattle are usually fed supplemental commercial brands of liquid protein, both in the field and feedlot.

Supplementation is very important when using cereal aftermath. Lyons, et al (1970) concluded that protein was the primary limiting factor in voluntary straw consumption. When this basic need was fulfilled, the capacity of the digestive tract became the limiting factor. The use of cereals (as a source of energy) did not alter digestibility or consumption of the straw (Kay et al, 1968).

Nitrate poisoning may be a problem with cereal aftermath when the crop has been stressed, especially during a drought (Anderson, 1976). Beards from the barley and certain wheat varieties commonly cause animal eye and mouth sores. Use of beardless varieties, such as club wheat, prevents this. Also, compaction of the digestive system can occur when residues make up a high percentage of the total diet.

Although levels of digestible nutrients in cereal aftermath have been measured, the results vary, probably underestimating the animals' nutrient intake. Quality and palatability of cereal aftermath usually increases when the crop has undergone water stress. Levels of crude protein tend to be higher for cereal produced on drier sites or in years with below average rainfall, probably due to the earlier maturation of crop plants. More nitrogen is trapped in the foliage and lower levels of fibrous materials (i.e., lignin) accumulate in the matured plant.

Another factor frequently overlooked is animal selectivity. Generally animals will consume the more digestible plant parts. Animals have been observed selecting for the leaves on stubble fields. After the first rains animals will begin to forage on the stems; rainfall softens stems and greatly reduces the availability of leaves. Chaff is also preferred over straw. Most nutrient analyses have shown crude protein levels to be twice as high in leaves and chaff compared to straw. The presence of weeds and other forage also play a role as cattle select preferred green plant material.

Some research has been directed toward treating cereal residues to increase digestibility. Pelleting straw has been shown to decrease digestibility, but increase intake and overall feed efficiency (Campling and Freer, 1966; Minson, 1963). The cost of pelleting straw has been estimated at around US $30 to $55 per metric ton (Anderson, 1976). Treating cereal residues with sodium hydroxide and calcium hydroxide have also been attempted (to a limited extent) to increase digestibility.

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XIII. INTEGRATION OF RANGE AND CULTIVATED LANDS

Zones where croplands and rangelands interface generally lie in a belt that receives more than 250 mm annual precipitation. Cultivated crops occupy areas with suitable soil and topographic characteristics; the remaining lands usually support animal grazing.

Livestock harvest significant amounts of forage annually from these lands. Whereas on cultivable portions forage consists of planted pastures, weedy fallow (or temporarily unplanted fields), and crop aftermath or residues, rangeland forage comprises either native or introduced palatable grasses, forbs, and shrubs. Rangeland suffering depleted forage resources often can be improved through reseeding or use of an appropriate grazing system. Abandoned cropland in many developing countries urgently needs reestablishment of suitable vegetational cover to reduce erosion losses. These lands, if provided proper followup management, could be seeded with valuable forage species thereby increasing their potential animal feed supply at least 100 percent, if not more. Use of this forage could relieve grazing pressure on the interspersed rangelands. Additionally, alternating forage and crops may generate increased livestock feed and concurrently benefit crop yields. The Australian ley farming system developed in the 1930's and now used in portions of many countries, is an outstanding example of a crops-forage rotation system.

A. Annual Forage Systems

Ley farming defines a system in which crops alternate with pasture leys. The pastures, as their main component, have annual legumes which are either cultivars of medics (*Medicago* species) or subterranean ("sub") clover (*Trifolium subterraneum*). The legume is free seeding, self regenerating, and dominant in the pasture phase of the rotation (Doolette, 1977). It provides soil nitrogen, improves the fertility and physical characteristics of the soil, helps control weeds and cereal diseases, and generates large quantities of forage which may be used by animals.

The ley system is based on several important principles that differ from other systems in semi-arid rainfed regions. Basically these revolve around the successful function of the legume plant (Doolette, 1977) and include:

-Adequate expression of the legume plant in terms of herbage production;
-Nitrogen accumulation and its dependance of rhizobia-legume symbiosis and phosphorus;
-The production of adequate seed, a percentage of which is "hard" and will not germinate in the fall. Hard refers to the seed characteristic that resists entry of water, thus preventing germination until the extreme heat of summer cracks the seed coat allowing germination the following fall. This is the mechanism whereby the legume regenerates itself after a short cropping phase;
-Maintaining the seed close to the soil surface by adopting shallow cultivation practices;
-Allowing legume seed to mature by delaying the time of initial cultivation;
-Exerting some control of grazing animals in an attempt to maximize seed production, soil fertility buildup, weed control, and animal income;
-A one year crop followed by one year pasture rotation, although this may vary.

nvironmental conditions that limit application of the ley system, mainly climatic, include those which prevent successful and economic expression of the annual forage legume (Doolette, 1977). Cultivars used in the system do not tolerate extreme cold temperatures; consequently, the system presently is restricted to areas with a Mediterranean, mild winter temperature climate. Under these climatic conditions, the annual legume variety displays vigorous winter-spring growth and produces large quantities of seed.

The amount of nitrogen fixed by a legume pasture in this system varies with soil type, legume stand vigor, the existing level of soil nitrogen, and efficiency of nodule forming bacteria (Webber, et al., 1976). An average stand can increase soil nitrogen by at least 60 to 70 kg/ha in one season, or the equivalent of approximately 300 kg of sulphate of ammonia (Webber, et al., 1976). Values up to 200 kg of nitrogen per hectare have been recorded. As an example of the potential impact of this system, the annual value of soil nitrogen from ley pastures in Australia exceeds $600 million annually (Carter, 1975). With proper application of phosphate to encourage productivity, this system provides the major feed requirements for some 180 million head of sheep in Australia.

Rotations in annual legume systems, while based on alternate year cropping, are varied depending on soil type, soil fertility levels, growing seasons, and density and vigor of the pastures. Farmers are also influenced by relative prices of crop and livestock products.

In some medic systems, farmers may grow one or two cereal crops for every reasonable medic crop. Less cropping may be wasteful because medics and subclover fix nitrogen most rapidly in the year after a cereal crop (Webber, et al., 1976). Subclover seldom survives a long cropping program; it may need to be resown after each sequence of crops. Examples of common legume-cereal rotations include:

(1) Legume-wheat (or barley)-legume-wheat (or barley); precipitation 350-475 mm, loam soil.

(2) Legume-legume-wheat-wheat (or barley); intensity of the legume phase depends on soil fertility level.
(3) Legume-legume-legume-wheat; erratic rainfall, sandy soil.

To help insure maximum forage for livestock and sufficient seed for regeneration, swards should become well established before grazing is permitted; that is, plants should have six to eight leaves. The pastures can produce hay if cut at the early flowering stage. At this stage hay has optimum feed value and the plants have the greatest chance to recover.

Taking into account environmental constraints and production goals, Doolette (1977) stated that the ley system could be profitably installed on some 15 million hectares in the Middle East and North Africa. He suggested that the following questions be considered when setting up the system in a new location:

- Is there an annual forage legume variety with growth pattern adequate for the particular environment?
- Is there a satisfactory rhizobial relationship?
- Are the seed coat characteristics adequate for satisfactory regeneration after the cropping phase?

A wide range of annual legume varieties are being developed and tested continually. As these come into use the area suited to the ley system will expand. In fact, expansion of the system into developing countries is occurring (Doolette, 1977). Successful implementation will rest on technologies already developed, but modified to fit local situations. A major objective will be to recognize and involve the particular social structures in each individual region.

B. Perennial Forage Systems

Lucerne (*Medicago sativa*), sainfoin (*Onobrychis sativa*), and other perennial legumes can be used in rotation with crops. Also, perennial grasses such as cocksfoot or orchardgrass (*Dactylis glomerata*), timothy (*Phleum pratense*), Harding grass (*Phalaris arundinacea*), several bromes (*Bromus* species), and others can be grown alone, or mixed with the perennial legumes, for direct pasturing by animals, or for hay production. These species generally involve longer term rotational cycles than the annual legume systems. Pasture production can be prolific, especially on lands where irrigation is possible, possibly increasing per hectare forage production several fold. Lucerne is particularly desirable where spring, summer, and early fall fodder is needed.

Hay can be made from these crops. The resulting vast quantities of stored forage provides animal feed for dry or dormant seasons or for feeding prior to breeding. In developed countries, lucerne or grass hay, or both, provide a major source of roughage for cattle and sheep. The same species also are stored in the form of silage.

Despite the seasonal character of forage in most developing countries, relatively little concerted effort to store forage has been demonstrated. Generally, animals must subsist on a very low nutritional

plane during periods of meager feed; starvation or nutritionally related diseases can result. Programs to increase forage production also should span storage which will help provide animals with an adequate, year-round forage supply. Animal performance--gain, reproduction, and disease resistance--hinges on proper year-round nutrition.

Forage can be stored in the form of hay, silage, crop by-products, aftermath or residues, and grain. Rangelands, if used judiciously, provide an additional form of storage. Range plants can tolerate a certain amount of grazing; beyond that point (their tolerance) they are unable to regain vigor and continue to produce forage. Plants grazed well above the tolerance point creates a reserve that can be tapped under extreme conditions so long as the following year's grazing patterns are adjusted accordingly. Also, certain shrub species can represent a sizable amount of standing forage for use during critical short forage periods.

Significant potential exists for increasing animal fodder in the rainfed cropland areas of developing regions. Increased forage from these areas will reduce grazing pressure on rangelands and permit more flexibility for implementing range improvement programs with proper follow-up management. Ultimately this situation can increase the forage quantity and quality from these lands while simultaneously reducing soil erosion.

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