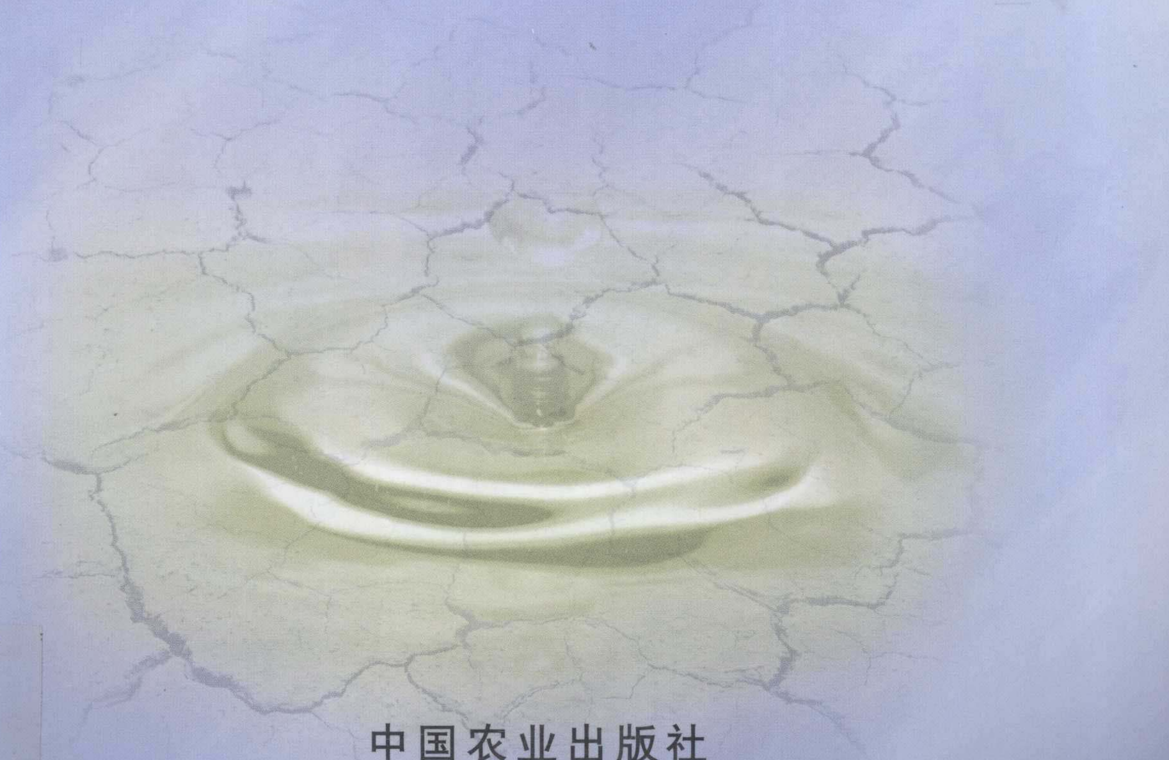
Proceedings of the International Workshop on Water-Saving Agriculture in Dryland Areas

国际旱地节水农业研讨会

论文集

国家自然科学基金委员会
国家外国专家局　编
西北农林科技大学



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前 言

农业是人类栽培作物、饲养动物的活动，因而离不开水的供应。恰如无水就无生物一样，无水也无农业生产。水是农业生产的命脉和物质基础，是“有收无收”的前提，决定着农业生产的成败，左右着农业生产水平的高低。

人口增长和工农业发展对水资源提出了更高的需求，而人口增长和工农业的大量消耗和污染又使可利用的淡水资源日益减少，因此而产生的全世界水资源危机成了世人关注的重大问题。这种情况在我国尤为突出。我国是全世界26个最缺水的国家之一，人均水资源只有世界平均水平的1/4；而农业又是我国国民经济中最主要的用水大户。水资源不足已产生了明显的压力，空间和时间的极端分布不匀又加剧了这一形势：80%的地表水资源分布在南方，北方仅占20%；而64%的可耕地却在北方。在北方地区中，西北尤为严重：面积约占全国1/3的西北地区，水资源只有全国总量的8.3%。水资源不足已成为制约我国农业乃至全国国民经济可持续发展的主要限制因素，直接危及一些地区人民的生存与发展；由缺水而引起的环境退化、土壤荒漠化、河流断流及沙尘暴迭起，已给人们的生存环境和全国经济发展带来了严重影响。西北地区由于水资源短缺所造成的这些环境问题更为严重和突出，不仅直接危害本地区人们的生存环境，而且波及下游，危及周边地区。

实施西部大开发战略，加快中西部地区的发展是国家面向21世纪的重大决策，而西北正是这一战略目标集中的主要地区。西北地区幅员辽阔，光热资源丰富，耕地相对较多，人口密度较低，有着发展农业的较大优势和增产潜力，也有着旱地农业的悠久历史。位于这一地区著名的黄土高原，历史上曾是森林郁蔽、绿草遍野、牛羊成群、五谷丰登之处。大约6000年前，这一地区的汾、渭河谷的肥沃土地上已经孕育出比较发达的原始农业。西周和春秋战国时代，黄河流域已经成为全国农业中心，以后再扩展到长江流域、东南海岸、长城北部。公元前121年，霍去病带领的十万多士兵在河西走廊建署固边，发展农业。当时所有河流的中、下游地区都发展了灌溉农业，黑河中下游灌溉农业闻名当时，以后又获得了金张掖、银武威之称。联结东西方有名的丝绸之路，象征着中国古代文化交流的第二次高峰的敦煌石窟穿过或位于这一地区。因此，这个地区不仅是中国农业发展的源地，也是中国文化的摇篮。在过去许多世纪与自然斗争中，这一地区的人民积累了管理旱地的丰富经验。新疆人民创造的坎儿井地下灌溉系统，至今仍灌溉着新疆广大土地。几千年来，中国人民有效地利用了旱区的水土资源，创造了大量的肥沃土壤。沙漠中的绿洲，如古代创造的塔里木河中下游形似

珍珠串一样排列着的绿洲、河西走廊的绿洲以及近代创造的马拉斯河谷绿洲，就是这种肥沃土壤的典型代表。旱地土壤管理既创造了生产力高的绿洲，也从整体上改善了一些生态环境。敦煌的绿洲土壤经过2000多年灌水和施肥的农业实践，耕层土壤加厚到2m以上；黄土高原地区，由于几千年施用有机肥料，形成了20～30 cm，甚至50cm的人造表层土壤，反映了这一方面的成就。

西北地区的农业生产对我国农业有着重大的贡献。从过去到现在，都是我国农业生产的重要基地之一，也是我国小麦、玉米、棉花、豆类和多种杂粮的主要产区。随着国家西部大开发战略的实施，西北地区越来越受到党和国家的重视。充分利用这一地区的自然优势，合理保护自然资源，持续发展这一地区的农业生产，不仅对满足当地人民生活需要，制止滥砍滥伐，实现退耕还林还草，增加植被覆盖，恢复良好生态系统，改善周边地区生态环境有重要意义，而且对扩大内需，促进各地区间经济协调发展，推动我国经济全面持续增长和全国均衡发展，维护社会稳定，最终实现共同富裕的总体战略目标都有重大作用。

制约西北地区农业生产的主要因子虽然是水分胁迫，但水资源仍然有着可挖掘利用的潜力。管理不善所造成的严重水资源浪费，设施不良所造成的灌溉渠系水分的大量渗漏，养分供应不足所导致的水分利用效率不高，措施不力所造成的水分大量蒸发，都说明了这种潜力。不少事实也为这种潜力提供了证据。例如，大量研究显示，产量并不与降水量同步增减，说明了降水并未发挥应有的作用；相同降水条件下不同田块产量的巨大差异又证明水分管理的意义和作用。

在保证生态环境用水，做到水与环境协调的条件下，充分挖掘天然降水潜力，有效地提高水资源的利用效率，是解决西北地区水资源短缺的关键所在，而要达到这一目标，实行节水农业是根本出路。近年来，农业节水与水资源可持续利用的问题已越来越受到世界各国的重视，进行了大量的研究工作。为了引进国外先进经验，总结我国节水农业的成就，有力地推动节水农业发展，由国家自然科学基金委员会、国家外国专家局主办，西北农林科技大学承办的“国际旱地节水农业研讨会”，于2001年8月6～10日在陕西杨凌国家农业高新技术产业示范区举行。这次研讨会的主要目的是总结我国节水农业所取得的成就；学习国外先进经验，引进国外节水农业的先进技术；培养人才，促进节水农业研究工作深入开展；进一步创造开展国际合作条件，使我国在节水农业方面的研究和应用逐步达到国际先进水平。

参加这次研讨会的有来自美国、以色列等国家的9名外国专家，有来自黑龙江、吉林、辽宁、北京、河北、河南、山东、山西、陕西、宁夏、甘肃、江苏、四川和新疆等地的80余名国内学者。国家自然科学基金委员会李主其副主任、国家自然科学基金委员会秘书处唐先明处长、国家自然科学基金委员会国际交流中心顾明达教授、王丽汴副处长、国家自然科学基金委员会工程与材料

学部水利学科李万红主任、西北农林科技大学常务副校长李靖教授、国家杨凌农业高新技术产业示范区张光强副主任等出席了开幕式；中国工程院院士、西北农林科技大学山仑研究员、西北农林科技大学李玉山研究员、蒋定生研究员、中国农业大学王学臣教授、西北农林科技大学李生秀教授等参加了研讨会。这次会议一直受到国家自然科学基金委员会生命科学部农学学科冯锋主任，国家自然科学基金委员会地球科学部地理学科宋长青主任和国家自然科学基金委员会工程与材料学部水利学科李万红主任的关心和支持。会议期间，国家自然科学基金委员会国际合作局韩建国局长临会指导工作，并与外国专家一起赴陕北考察；筹划和关心这次会议的国家自然科学基金委员会国际交流中心袁幼新主任因事未能参加会议，但该中心顾明达教授、王丽汴副处长由筹备到会议结束，全过程地参加和指导工作。

这次国际旱地节水农业研讨会有15位国内和5位国外旱农专家分别作了专题报告。围绕节水主题，美国西得州农工大学教授、旱农研究所所长、国际著名旱地农业专家Stewart博士报告了灌溉的理论和应用，介绍了国际节水农业的研究历史、概况、现状和进展及现已取得的理论和技术成果、美国节水灌溉中存在的问题及今后研究的方向。美国Colorado大学教授，著名土壤学家和农学家，在旱地农业生产和保水耕作方面有突出贡献的Peterson博士介绍了旱地农业生产体系中高效产业结构，覆盖耕作的实践、效果和存在的问题。以色列农业研究机构Volcani中心，土壤、水、环境研究所，著名水分、养分管理专家Asher Bar-Tal博士介绍了设施栽培条件下肥水灌溉（Fertigation）制度，介绍了肥水灌溉的原理，不同介质中肥水灌溉的养分组成原则和配方，肥水灌溉在设施农业中的应用，肥水灌溉存在的问题和解决途径。在美国农业部Bushland水土保持耕作研究室任职并兼任Texas和Oregon农业试验站工作的作物生理学家Payne博士报告节水农业的生物学基础，作物水分利用效率的潜力及提高作物水分利用效率的途径。美国西得州农工大学农学部主任，得州农业与自然资源杂志主编Thomason教授报告草原管理的原则，草地与畜牧业的协调与统一，提高草地水分和养分利用效率的途径和经验，草原发展中存在的问题及对策。美国西得州农工大学农业与生命科学助理副校长James Clark教授就美国畜牧业发展做了介绍。

在研讨会上，我国学者就节水的研究成果和经验进行了广泛的交流。王学臣教授报告了我国节水和抗旱的生物学和生理学研究进展，李生秀教授报告了覆盖耕作的应用及存在的问题，康跃虎教授报告了我国节水灌溉的实践和进展，王静教授介绍了集水农业的研究成就和应用结果，张岁岐研究员报告了节水农业中的生物问题。在报告和交流过程中专家就有兴趣的问题进行了热烈的讨论。

会议还就国际合作问题进行了专门讨论，西北农林科技大学和美国西得州农工大学的专家就两校合作进行旱地水分管理研究、合作发表研究论文与出版学术专著、

交换科研人员等事项进行了充分的讨论，并在会后正式建立了两校合作关系。

与会期间，国内外学者参观了杨凌国家节水农业示范园、秦川节水设备公司、黄土高原土壤侵蚀与旱地农业国家重点实验室人工降雨大厅、农业水土工程重点实验室、昆虫博物馆及杨凌示范区其他科技示范基地。研讨班结束后，国内学者分别考察了渭北旱原旱地农业和关中灌区农业生产状况；外国专家考察了我国黄土高原的水土流失和陕北安塞生态农业试验站。

这次研讨会圆满完成了各项会议日程，达到了预期效果。报告和交流内容涉及节水农业的各个方面，反映了国外和国内近年来的工作成果，对我国节水农业理论和技术体系的进一步发展有着十分重要的意义。通过会议交流了经验和学术观点，结交了朋友，增强了友谊，与会人员对这次会议的组织、安排和活动非常满意。这次会议之所以能取得这样好的效果主要在于基金委的筹划和指导，基金委几个学科的支持和关心，西北农林科技大学领导的重视和各处室的支持，西北农林科技大学资源环境学院同志们的认真工作和忘我劳动，也在于全国农业科技工作者的关心和合作。我们愿在本书出版之际向主办和筹办这次会议以及关心和支持这次会议的各单位领导、同志和朋友表示衷心的感谢！

会议之后我们就组织编辑会议论文集，原计划在半年内编好付印。但当我们着手这一工作时才发现有不少困难。主要是提交的文稿大都未按约稿规则撰写，有的著录不全，有的图表残缺，有的又失之过简，符合要求可以直接刊用者数量有限。为了能够充分反映这次会议的成果，我们又向与会专家广发电子邮件，要求重新撰写或修改所提供的论文。经过不少与会专家的支持和西北农林科技大学资源环境学院同志的认真工作，历时一年有余，终于完成了这本论文集的编辑工作。

本次会议共收到论文 44 篇，其中一篇已在其他杂志发表，一篇资料不全，因而共收入论文 42 篇。

论文集分两部分，第一部分是国外专家的论文。编辑时统一了格式，在相应的文字部分插入了专家报告时图片（幻灯片），添加了图名，以充分反映报告内容；除个别论文外，文字基本未动。第二部分是国内专家的论文，其中少数以英文撰写，多数使用中文。对这部分论文，我们也统一了格式，校正了一些错误，修改了部分文字，删去了图表中的英文注释。为了查阅方便，论文按英文、中文次序排列。

智者千虑，必有一失，何况编者不是智者。此书虽然经过一番努力，但一定还存在着不少问题。衷心希望读者予以批评指正。

李生秀

2003 年 5 月于西北农林科技大学

目　　录

Water Management for Dryland and Irrigated Cropping Systems in Semiarid Environments

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The People's Republic of China and the United States are the two largest agriculture producing countries in the world. Both of these countries have large amounts of land in semiarid regions and they both have extensive areas of these lands under irrigation. Prior to discussing water management strategies, it is helpful to have some understanding of some of the differences and similarities of these two agricultural giants. Data from 1961 to 2000 for arable land, irrigated land, fertilizer usage, and production of selected cereal crops are shown in Tables 1 and 2 for the United States and the People's Republic of China, respectively. Although production of cereals has increased dramatically in both countries, there are some startling differences. While, the amount of arable land in the United States remained fairly stable over the 40-year period, that in the People's Republic of China made a dramatic increase during the 1980s. The amount of irrigated land in the United States increased significantly during the 1960s and 1970s but has changed little in the past two decades while irrigated land in the People's Republic of China has continued to increase although at a somewhat slower rate. The United States has about 1. 4 times more arable land than the People's Republic of China, but less than 0. 4 as much irrigated land. The largest divergence between the two countries has been in fertilizer usage. As with irrigation, the big increases in fertilizer usage in the United States occurred in the 1960s and 1970s and since that time there has been a decline. Although not shown in Table 1, there was also a large increase in fertilizer usage during the 1950s. The large increases in fertilizer usage in the People's Republic of China began in the 1970s and really exploded during the 1980s. In 1961, the People's Republic of China used only about 1/10 as much fertilizer as the United States but almost twice as much in 1998. However, it appears that the usage has somewhat peaked in both countries.

The areas seeded to millet, sorghum, wheat and corn are also presented in Tables 1 and 2. These crops were selected because wheat and corn are generally grown in more favored environments or under irrigation while millet and sorghum are often grown in areas of less precipitation. Millet is not a major crop in the U. S. and there has been relatively little change in either yield or area over the past 40 years. In China, however, there has been a very large

Table 1 Area and yield of selected cereal crops in the United States and areas of arable and irrigated lands

	1961	1970	1980	1990	1995	2000
Millet						
Area (1000hm^2)	112	150	120	180	190	150
Yield (kg/hm^2)	1 155	1 327	1 371	1 500	1 501	1 109
Sorghum						
Area (1000hm^2)	4 445	5 491	5 064	3 678	3 340	3 125
Yield (kg/hm^2)	2 744	3 164	2 906	3 959	3 488	3 820
Wheat						
Area (1000hm^2)	20 870	17 629	28 784	27 965	24 667	21 460
Yield (kg/hm^2)	1 607	2 087	2 251	2 657	2 721	2 820
Corn						
Area (1000hm^2)	23 323	23 212	29 526	27 095	26 389	29 434
Yield (kg/hm^2)	3 918	4 544	5 712	7 438	7 123	8 398
Arable land (1000hm^2)	180 630	180 735	188 755	185 742	176 950	176 950**
Irrigated land (1000hm^2)	14 000	16 000	20 582	20 900	21 400	21 240**
Fertilizer (1000mt)	7 646	15 535	21 480	18 587	20 038	19 774**
Population (millions)*	186	210	230	254	267	278
Total cereals/capita (kg)*	880	890	1 172	1 230	1 069	1 237

＊ 1961 values based on 1960 population.

＊＊ 1998 values.

Table 2 Area and yield of selected cereal crops in China and areas of arable and irrigated lands

	1961	1970	1980	1990	1995	2000
Millet						
Area (1000hm^2)	7 395	6 915	3 874	2 279	1 522	1 385
Yield (kg/hm^2)	974	1 411	1 406	2 008	1 984	1 509
Sorghum						
Area (1000hm^2)	6 803	5 224	2 696	1 571	1 238	966
Yield (kg/hm^2)	927	1 686	2 517	3 678	3 921	2 893
Wheat						
Area (1000hm^2)	25 568	25 435	29 191	30 754	28 861	26 648
Yield (kg/hm^2)	559	1 148	1 891	3 194	3 542	3 729
Corn						
Area (1000hm^2)	15 215	15 838	20 372	21 483	22 849	22 543
Yield (kg/hm^2)	1 185	2 089	3 079	4 525	4 918	4 670
Arable land (1000hm^2)	103 384	100 045	96 917	123 672	124 053	124 144**
Irrigated land (1000hm^2)	30 402	38 113	45 467	47 965	49 857	52 582**
Fertilizer (1000mt)	728	4 407	15 335	27 027	35 181	35 078**
Population (millions)*	657	831	999	1 155	1 221	1 278
Total cereals/capita (kg)*	167	242	281	355	343	320

＊ 1961 values based on 1960 population.

＊＊ 1998 values.

decrease in area seeded to millet. Likewise, there has been a sharp decline in the area seeded to sorghum in China, and a much smaller decline in the U. S. This suggests that land expansion into drier areas for growing crops under dryland conditions is not occurring in these countries. In some countries, particularly several in Africa, have shown large increases in areas seeded to millet and sorghum suggesting that crop production is expanding into drier areas.

The area seeded to wheat in the U. S. increased significantly during the 1970s but has declined in more recent years while there has been much less change in the area seeded to corn. In China, the area seeded to these crops has increased considerably, but in recent years there has been little change in corn area but a significant decline in wheat area. In both countries, however, wheat and corn are major crops in comparison to sorghum and millet.

1. Dryland Farming

Dryland farming is the growing of crops, often coupled with livestock production, with limited precipitation. Dryland systems emphasize water conservation, sustainable crop yields, limited inputs for soil fertility, and wind and water erosion constraints. Dryland farming occurs largely in semiarid environments. The concept of semi-aridity can best be related to crop plants and native grassland. The dry boundary of a semiarid region generally lies at the edge of the area where production of dryland annual crops is not possible during a majority of the years. However, satisfactory grass production regularly occurs over most of the surface, and annual cropping can be practiced in occasional years in favored spots such as areas receiving runoff. The wet boundary of a semiarid region occurs where droughts do not substantially limit the production of crops in a majority of the years but dryland crops can and do fail due to occasional drought. Irrigation is widely practiced in semiarid regions when water resources are available and economic conditions are favorable. This paper will discuss water management in semiarid environments because water management in these regions is different than that for either arid regions where irrigation is practiced, or in humid areas where rainfed cropping is dominant. In arid regions, there is generally no production of crops without irrigation and the amount of rainfall is so limited that it can be essentially ignored in water management. In the sub-humid and humid areas, water management often involves dealing with excess water during parts of the year and droughts do not occur often enough and with enough severity to warrant irrigation development even though water resources may be available. The author considers agriculture in these regions as rainfed agriculture and distinctly different from dryland agriculture.

Water management of both the precipitation and irrigation water is different in semiarid environments than for other environments. Dryland cropping in these environments is totally dependent on the scarce and highly variable precipitation so water conservation must be the foundation of any system. Irrigated cropping systems in these regions must also consider the precipitation because failure to do so can result in too much water or large losses due to runoff and percolation. As a general rule, the precipitation in irrigated agriculture in semiarid regions should be considered as the primary source of water and irrigation as a secondary or supplemental source. This is because the source of irrigation water in semiarid regions is often limited so there is generally much more land suitable for irrigation than there is water available for irrigation. Since some crop production in these areas is feasible without irrigation, the goal should be to use the limited irrigation resources to supplement the precipitation and increase crop production. Therefore, in semiarid environments, conservation of the scarce and highly variable precipitation should be the first priority of both dryland and irrigated cropping systems.

Although semiarid environments differ in many ways, they all have four unique keys. These keys involve environmental perception, proper resource management, and ability to react and respond to a wide range of environmental and political factors.

Key 1. No growing season is or will be nearly the same in precipitation amount, kind, or range, or in temperature average, range, or extremes, as the previous growing season. Although this key is critical in any rainfed system, it requires absolute attention in dryland farming. Crop cultivation requires an adjustment every year, which leads to the second key.

Key 2. Crops cannot be planned or managed to be the same from season to season. Most of the world's agricultural practices in either humid or arid areas have some predictability on an annual basis. In semiarid climates, however, even highly mechanized, technically advanced, commercial farms such as those in the High Plains of North America or the outback of Western Australia do not have sufficiently stable production for the individual or government to count on a given production figure for the following season.

Key 3. The soil and moisture resource does not remain the same for any long period of time once agriculture is introduced into a semiarid region. A generalization necessary to support this key is that soils of most semiarid lands developed under grass on relatively flat topography. The competition for moisture and nutrients to produce crops requires removal of the protective grass cover. Because the crops are annual and dependent on precipitation, severe drought often leaves the soil highly vulnerable to wind erosion.

Key 4. There is abundant sunshine due to many cloud-free days. This key has potential benefit and is shared with most arid climates. Abundant sunshine means higher temperatures that induce rapid growth, but it also creates a situation that demands careful management of soil moisture. Warm seasons, high sun, cloud-free conditions stimulate growth, but also increase evaporation and transpiration. It is possible for a grain crop to mature rapidly due to several weeks of sun-drenched, rainless conditions and desiccate just days before ripening. It is equally possible for a few mm of precipitation to occur at almost the last moment and produce a good grain crop.

These keys must be considered regardless of whether crops are produced under dryland conditions or irrigated conditions.

2. Dryland Cropping Systems

Opportunities for improving dryland farming in semiarid regions should be considered with enthusiasm, but tempered with realism. Because lack of water is the dominant constraint in dryland farming regions, water management must be considered in every farming decision. There are three components of a successful dryland farming management system - retaining the precipitation on the land; reducing evaporation; and utilizing crops that have drought tolerance and fit the rainfall pattern. Although these components have been known for centuries, new technologies and knowledge continue to emerge that improve water management in water deficient areas. Some of these technologies and the principles on which they are based will be discussed.

Climate and soil are the two most important factors that determine the ultimate sustainability of dryland farming systems. These factors are so closely related that they can hardly be considered separately. Soils in dryland areas are generally inherently lower in fertility because they are usually lower in soil organic matter and soil organic matter is closely associated with soil fertility and the chemical and biological processes. Soil organic matter also plays a vital role in the soil physical properties that are so important in storing and utilizing water. An important relationship often overlooked is that for most agricultural soils, degradative processes such as soil erosion, nutrient runoff losses, and organic matter depletion are going on simultaneously with the beneficial effects of conservation practices such as crop rotations, conservation tillage, and recycling of animal manures and crop residues. As soil degradative processes proceed and intensify, soil quality and productivity decreases concomitantly. Conversely, soil conservation practices tend to slow these degradative processes and increase soil productivity. The potential productivity of a particular soil at any point in time is the result of ongoing degradative processes and applied conservation practices. In arid and semiarid environments the most serious degradative processes are soil organic matter decline, soil erosion, and associated depletion of plant nutrients. In general, it becomes more difficult to balance soil degradation processes with soil conservation practices as the climate becomes either drier or hotter, and much more difficult when both of these climatic factors increase simultaneously. This is because the rates of soil degradation processes usually increase in hot, dry areas. Studies have reported that soil carbon values in Canadian prairie soils decreased about 50% as a result of 65 years of cultivation. In contrast, only 6 years of cultivation in a Brazilian semiarid thorn forest reduced the soil carbon content by 40%. Perhaps even more important, the soil conservation practices needed to offset soil degradation processes become exceedingly more difficult to implement and manage in hot, dry areas. Therefore, the resilience of soils in dryland regions is quickly and greatly weakened and can lead to desertification that has both physical and socio-economic consequences.

In the Great Plains of the United States, a combination of drought, excessive tillage, and the use of fallow that left the soil bare for up to 16 or more months between crops led to serious wind erosion in the 1930s. This resulted in the infamous Dust Bowl that is one of the worst ecological disasters on record. The Dust Bowl had enormous consequences not only on the soil resource base, but on social and economic conditions as well. Wind erosion in the area is largely controlled today by using less tillage and the tillage that is used leaves a substantial portion of the crop residues on the soil surface to lessen the potential for wind erosion.

At the present time, wind erosion in the People's Republic of China is increasing. According to Brown (2001), wind erosion has increased significantly in Inner Mongolia, Gansu, Qinghai, Ningxia, and Xinjiang. These provinces have increased cropland areas significantly in recent years to offset cropland that is decreasing in Guandong, Shandong and Jiangsu because of urban expansion and industrial construction. This is somewhat analogous to the conditions that led to the Dust Bowl in the United States in that cropland expanded into more marginal areas. As discussed above, it is much more difficult to develop sustainable cropping systems in areas where rainfall is lower and temperatures are higher. Degradative processes, particularly soil organic matter decline, accelerate and wind erosion can become serious.

Clearly, the most important steps in dryland farming are to capture, store, and utilize the highly variable and scarce precipitation. This can be done by two different management strategies - in situ water conservation and water harvesting. In situ water conservation aims at preventing runoff and keeping the rainfall, as much as possible, where it falls and then minimizing evaporation to the extent feasible. Water harvesting is the collection and concentration of rainwater and runoff and its productive use for irrigation or for consumption by people and livestock. Water harvesting practices are often designed to enhance water runoff so that it can be collected and used later, often at another site. In both cases, water management strategies should be accompanied by utilizing drought tolerant crop varieties.

3. Water Use Efficiency

Water use efficiency is the units of harvestable produce obtained for a given unit of evapotranspiration, and commonly expressed as kg/m^3. Evapotranspiration includes the amount of water used as transpiration by the crop and evaporation from the soil surface between the time the crop is seeded until it is harvested. This includes seasonal precipitation plus any change in the amount of plant available soil water during that period plus any additional water from irrigation. For cereal crops, the harvestable produce is generally considered the grain. Studies from various parts of the world report that water-use efficiencies of fall-planted irrigated spring wheat is frequently in the range of 1.0 to 1.2 kg/m^3. Some studies reported values as high as 1.5 to 1.9 kg/m^3. The highest values were often reported under deficit conditions, especially when irrigation water was applied in relation to critical stages. The stage between boot and heading was particularly critical. Much lower efficiencies, however, were reported for winter wheat grown under severe water deficits in the southern High Plains of the U. S. In 25 years of dryland wheat after summer fallow, water use efficiencies averaged 0.35 kg/m^3 for average yields of 1.1 Mg/hm^2. These values were about one-half those for irrigated wheat grown at the same site over a wide range of water deficits with yields of 3 to 6 Mg/hm^2.

Theoretically, biomass production is directly related to transpiration and there is a straight-line relationship indicating that for every unit of water transpired through the crop leaves, there is a corresponding unit of biomass production. The slope of the line is crop-dependent and also climate-dependent. For example, maize will have a steeper slope than wheat, and wheat grown in a sub-humid region will have a steeper slope than wheat grown in a semiarid region. When leaves open their stoma to allow carbon dioxide entry for photosynthesis, water is lost and the drier the climate, the more the water loss. It is also important to note that the line relating biomass production and transpiration passes through the origin showing that transpiration does not occur in the absence of biomass production. In actual field situations, there would be some water lost by evaporation from the soil surface in addition to that lost by transpiration, and if biomass production is plotted as a function of evapotranspiration, the line is shifted to the right and does not pass through the origin. For cereal crops, producers are usually more interested in grain yield than biomass yield so the most important relationship is that between cumulative evapotranspiration and yield of grain. Again, the slope of the line and the point where it intersects the X axis are dependent on both the climate and the crop, but the important fact is that there is a certain amount of evapotranspiration required before any grain is produced and beyond that point, there is theoretically a uniform amount of grain produced for each additional unit of water used by evapotranspiration. In practice, however, the amount of grain produced for an additional unit of water can vary considerably because of the timeliness that the water is received by the crop. Additional water received during a critical growth period can increase yield more than the same amount of water received during a less critical time. This relationship shows the importance of a small amount of additional stored water at the time of seeding, or small amounts of supplemental irrigation water.

4. Irrigated Farming in Semiarid Regions

Because the lack of water is the primary constraint for crop production in semiarid regions, irrigation is very common and is generally practiced to the fullest extent that water resources are available. However, there is generally more land suitable for cultivation in these areas than there is water available for irrigation so dryland farming and irrigate farming are both commonly practiced. Both types will often be practiced on different fields of the same farm. Irrigation in semiarid regions, however, mainly occurs on land that would be dryland farmed if irrigation water was not available.

The relationship between grain yield and seasonal evapotranspiration discussed earlier is why supplemental irrigation is so effective in semiarid regions. There is generally sufficient precipitation to meet the threshold value required for grain production and to produce some grain. Therefore, additional water added by irrigation can result in a very significant increase in grain yield.

The focus of any irrigation system should be on maximizing the evapotranspiration component with added water and minimizing losses such as runoff and percolation. This is generally more difficult under semiarid conditions than under arid conditions because of the higher rainfall amounts received in semiarid regions. Also, rainfall in these regions frequently range from less than 50% of average to more than 200% of average. Large rainfall events, particularly soon after an irrigation, can result in high losses by surface runoff and percolation below the root zone.

A hypothetical example, adapted from Howell (1990) illustrating the relationships between water supply, evapotranspiration, biomass yield, and grain yield, is presented in Figure 1. The total water supply is the sum of the plant available soil water in the profile at the time of seeding, the gross amount of irrigation water added during the growing season, and the rainfall received during the season. In the example, the sum of the rainfall during the growing season and plant available soil water was 250 mm. This resulted in a dryland yield of approximately 6 Mg/hm^2 of biomass production and about 2 Mg/hm^2 of grain. The example also indicates that about 75mm of water use was required before any dry matter was produced and about 150 mm was required before any grain was produced. This hypothetical example further indicates that about 1 200 mm of irrigation water was required based on the implied application efficiency, application uniformity, inherent soil variability, and irrigation water salinity to obtain maximum crop production. The 1 200 mm added irrigation to supplement the 250 mm of rainfall and stored soil water resulted in a total water supply of 1 450 mm and resulted in maximum aboveground biomass production of 24 Mg/hm^2 and maximum grain yield of about 11 Mg/hm^2. As discussed earlier, the slopes of the biomass production line and the grain production line are determined by the crop species and the environment (evaporative demand as characterized by either potential ET or vapor pressure deficit). The slopes of the biomass and grain lines are different because of the difference in partitioning between dry matter and grain. The harvest index, defined as the ratio of grain to the aboveground dry matter, is generally much lower when the grain yield is low as compared to a high yield. In this example, the harvest index for the dryland yield was 0. 33 (2/6) compared to 0. 46 (11/24) for the maximum yield. Prihar and Stewart (1990) concluded that there was a genetic potential for the harvest index of a crop species that would be achieved if a crop could be grown in the absence of stress. They estimated the upper-bounds of grain yield vs. dry matter yield for grain sorghum, maize and wheat from existing reports in the literature. The genetic potential harvest index values for grain sorghum ranged from 0. 48 and 0. 53, and from 0. 58 to 0. 60 for maize. The extent that the harvest index values of these crops is below the genetic potential value is a reflection of the amount of stress that the crop experienced. The stress can be either biotic or abiotic, but the most common stress experienced in dryland areas is climate.