RAINFALL HARVESTING AND MANAGEMENT FOR SUSTAINABLE AGRICULTURE IN WATER STRESSED / SCARCE REGIONS (Theme 3)

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1. Introduction

This paper attempts to describe rainfall harvesting and management practices (**theme 3** of the WG Drought mandate on drought management) in the ten countries represented on the WG Drought. Rainfall harvesting is taken to mean methods of maximising the effectiveness of rainfall in food production, at the location where the rain falls. It therefore includes methods of maximising the use of direct rainfall on irrigated areas, but not the storage of water which is then conveyed to another location for irrigation.

Overlaps with **theme 1** (Drought management strategies in water stressed / scarce regions) and **theme 2** (Coping with water scarcity) have been avoided as far as possible. However some overlapping is unavoidable.

The following table, using data from the ICID website, presents some basic comparisons of the ten countries.

Country	**Total geographic area (Mha)**	**Arable and Permanent Crop (APC) area as % of total area**	**Irrigated area as % of APC area**	**Population mid 2010 (Millions)**	**Cereal Production 2009 (MT)**
Australia	774.1	5.7	5.7	22.4	34.9
Chinese Taipei	3.60	27.5	45.8	23.2	1.3
India	328.7	51.5	36.8	1,188.8	248.8
Iran	164.8	11.3	48.5	75.1	20.8
Italy	30.1	57.0	28.2	60.5	17.4
Japan	37.8	12.1	54.5	127.4	11.5
South Korea	9.97	18.3	55.5	48.9	7.4
Turkey	77.9	33.4	20.5	73.6	33.6
UK	24.3	24.9	1.4	62.2	22.0
USA	962.9	18.0	14.3	309.6	419.8

There are obviously huge variations in country size, climate, extent of irrigation and population density. This is likely to mean that drought management strategies vary widely between countries.

Contributions from other countries have also been received, and these are listed and summarised in Section 6. They tend to be very specific and detailed.

2. How Rainfall management is approached

2.1. Climate, rainfall and runoff

2.1.1. Australia

Rainfall and runoff in Australia are extremely variable. Even on the most reliable streams the ratio between maximum and minimum annual runoff is about 12 to 1, and on some major rivers it is hundreds or thousands to 1. On the Darling River, which together with the Murray forms the longest river in the country, the ratio is infinity, because the Darling can cease to flow for more than a year at a time.

On average it is estimated that only about 15% of rainfall appears as surface water runoff and perhaps 1% reaches groundwater aquifers. The rest evaporates or is evapo-transpired.

Australia is a large country and can be divided simplistically into three climatic zones:

Tropical / sub tropical
This zone typically has wet summers (wet season) and dry winters (dry season). In many areas the dry season is almost completely free of rain. Crops can be grown readily during the wet season and at the start of the dry, and with irrigation a second crop may be possible in the dry season.

Agricultural production is limited more by lack of markets, difficulties in controlling pests, and lack of suitable land than by lack of water (Ref 1). Surface and groundwater resources are generally well connected, so any increase in irrigation is likely to rely on groundwater. However lack of suitable land will probably limit any such increases. The present dominant agricultural use is cattle grazing.

Arid
Much of the country, particularly in the interior, can be classed as arid. Average rainfall is low and variable, with no marked seasonal patterns. With one or two exceptions (such as Carnarvon in Western Australia) any agricultural pursuits are low intensity such as cattle grazing. Cropping is possible only with irrigation and is very limited. Groundwater is an important source of water and in some cases is being “mined” as replenishment rates are close to zero.

Temperate
The southern part of the country can be classed as temperate Rainfall is mostly in winter and spring, and summer and autumn tends to be dry and warm to hot. Quite large areas are irrigated, particularly in the southern Murray-Darling Basin, and irrigation is supported by storages supplied mostly by the small alpine areas. In many cases water is stored not only for use later in the year, but for use in future dry years. Dryland cropping is also practiced extensively. Other agricultural enterprises include a large sheep industry, dairying, horticulture and viticulture. Australia exports much of its food production, in particular wheat and other grains, dairy products, fruit and wine.

Irrigation varies from areas that are almost fully dependent on irrigation water to those that are mostly rain fed, and require only occasional supplementary irrigation. In areas where rainfall is a significant contributor it is clearly advantageous to use the rainfall as effectively as possible and so minimise the need to call on irrigation water.

Climate change is expected to lead to drier and more variable conditions in much of the south, in particular in the Murray-Darling Basin which produces much of the agricultural output of Australia. The tropical north is not expected to become consistently either drier or wetter

2.1.2. Chinese Taipei (Taiwan)

Taiwan has a subtropical island climate system characterised by highly abundant rainfall. However, affected by the geographical terrain and monsoon winds of the island, areas and periods of rainfall are scattered and uneven. Demand for water, especially for irrigated agriculture, is of course greatest during the drier part of the year. The result is that rainfall cannot fully provide for water demands.

It is believed that rainfall has declined by 0.9% over the past ten years and runoff has declined by 4.3%. Projections are that by 2050 winter rainfall will decrease by around 5% to 10% and summer rainfall will increase by a similar amount. Furthermore, a growing trend has been noted in the longest chain of no-rainfall days. These changes may seriously affect the grain and food supply in the country.

2.1.3. India

The climate of India resolves into six major climatic subtypes; their influences give rise to desert in the west, alpine tundra and glaciers in the north, humid tropical regions supporting rain forests in the southwest, and Indian Ocean island territories that flank the Indian subcontinent. Regions have starkly different—yet tightly clustered—microclimates. The nation is largely subject to four seasons: winter (January and February), summer (March to May), a monsoon (rainy) season (June to September), and a post-monsoon period (October to December).

The Thar Desert in the northwest and the Himalayas in the north work in tandem to effect a powerful monsoonal regime. As Earth's highest and most massive mountain range, the Himalayan system bars the influx of frigid winds from the icy Tibetan Plateau and Central Asia. Most of Northern India is thus kept warm or is only mildly cold during winter. The same thermal dam keeps most regions in India hot in summer.

Though the Tropic of Cancer – the boundary between the tropics and subtropics—passes through the middle of India, the bulk of the country can be regarded as climatically tropical. As in much of the tropics, monsoonal and other weather patterns in India can be wildly unstable: epochal droughts, floods, cyclones, and other natural disasters are sporadic, but have displaced or ended millions of human lives. There is widespread scientific consensus that South Asia is likely to see such climatic events change in frequency and increase in severity due to global warming.

Indian agriculture is heavily dependent on south west monsoon, in particular drives the *kharif* crop production in large parts of the country. Delay in onset of monsoon, mid-season breaks or early withdrawn have severe bearing on the growth and yields of *kharif* season crops particularly under rain fed conditions. Despite the development of vast irrigation infrastructure in the country 60 per cent of cropped area still remains rain fed and its success completely depends on the timely onsets and even distribution of monsoon rainfall.

2.1.4. Iran

Iran is located in a mainly arid-semiarid region with an average annual precipitation of 245 mm. The climate varies from humid in the north on the coast of the Caspian Sea to ultra-arid in the central plateau. Western and northern parts are mainly mountainous with a semiarid Mediterranean climate. Although all of the southern part is located at the coast of the Persian Gulf and the Oman Sea, southern, central and eastern parts of the country are classified as hot desert areas.

Average annual precipitation also drastically varies from less than 150 mm in one third of the country to over 1000 mm in 0.4 % of the country. As shown in the following table, over 90% of the area in Iran receives less than 500 mm, while less than 10% gets more than 500 mm of precipitation.

Precipitation Distribution in Iran

Area %	Annual Precipitation Range (mm)
0.4	+1000
9.14	500-1000
29.23	300-500
32.20	150-300
29.30	<150

2.1.5. Italy

The inland northern areas of Italy have a relatively cool, mid-latitude version of the humid subtropical climate, while the coastal areas and the peninsula south of Florence generally fit the Mediterranean climate profile.

Between the north and south there can be a considerable difference in temperature, above all during the winter: In some winter days it can be −2°C and snowing in Milan, while it is 8°C in Rome and 20°C in Palermo. Temperature differences are less extreme in the summer.

The east coast of the Italian peninsula is not as wet as the west coast, but is usually colder in the winter. The east coast is occasionally affected by the cold bora winds in winter and spring.

Summer is usually more stable, although the northern regions often have thunderstorms in the afternoon/night hours and some grey and rainy days. So, while south of Florence the summer is typically dry and sunny, in the north it tends to be more humid and cloudy. Spring and autumn weather can be very changeable, with sunny and warm weeks (sometimes with Summer-like temperatures) suddenly broken off by cold spells or followed by rainy and cloudy weeks.

Both the mountain chains can see up to 5–10 m of snow in a year at 2,000 m; on the highest peaks of the Alps, snow may fall even during mid summer, and glaciers are present.

Average precipitation (1971 to 2000) can be summarised for regions of Italy as follows:

Average Precipitation - Italy

Region	Average Annual Precipitation (mm)
Southern	350 – 1000
Central	450 – 900
North Western	900 – 1100
North Eastern	600 - 1400

2.1.6. Japan

General

Situated northeast of the monsoon track that fuels the heavy rains across southeast China, the Japanese islands experience a relatively mild maritime climate. Except for Hokkaido and the subtropical Okinawa region, the weather is mostly temperate, with four seasons. Each season has its own distinct characteristics, emphasized by an early summer rainy season affecting many areas, and a typhoon season that runs from July through September. Hot, moisture-laden south easterly winds blow across the islands from the Pacific in summer. Cold, north westerly winds originating in Central Asia bring winter weather to Japan from Korea and China.

Though dominated by the maritime Pacific air mass, Japan has a diverse climatic range from north to south and mild, sunny weather can be found somewhere in the country at almost any time of year. Broadly speaking, there are four main climatic regions in Japan: the Pacific coastal region, which has a high summer rainfall; the Japan Sea coastal region, with its heavy winter snows and low temperatures; the inland region, where rainfall is generally lower; and the subtropical to tropical climate of the Ryukyu Island chain. Despite this general pattern however, the archipelago stretches over a vast distance from north to south and has so many mountain ranges that climatic conditions vary a great deal from season to season and from place to place.

Temperature
Down the length of the Japanese island chain, temperatures range from cold-temperate to tropical. Wakkanai, a city on the northern end of Hokkaido, has an average annual temperature of 6°C (44°F). Situated on the Kansai Plain on the Pacific side of the island of Honshu, Tokyo has an average annual temperature of 15°C. On the island of Okinawa in the Ryukyu Islands, the city of Naha has an annual average temperature of 22°C.

Rainfall
While generally rainy and humid most of the year, Japan's month-long wet season from June to July brings the heaviest rainfall to most parts of the country. The frequent rainfall combines with warm temperatures to keep the islands in the tropical and subtropical regions green throughout the year. The city of Hiroshima, in western Honshu, averages a sizeable 1,603 mm of rain each year. Tokyo, further east near the Pacific, receives an annual average rainfall of 1,460 mm. The city of Sapporo, on Hokkaido, averages 1,158 mm of precipitation per year. The southern end of the Kii Peninsula is known for a heavy annual rainfall exceeding 4,000 mm.

Average precipitation in Japan is about 1,700 mm a year, which is nearly twice as much as the world average of 970 mm (Sato, 2001). It is yet not enough for rice cultivation, carried out between April and September. Rice is the most water consuming crop in Japanese agriculture and rice farming is the biggest water consuming sector in Japan. There is less demand for water for agriculture today compared to the past. In 1969, rice cultivation area was at its peak with 3.17 million ha cultivated out of 3.44 million ha of paddy fields. Today rice cultivation accounts for 1.58 million ha out of 2.47 million ha of total available paddy fields. Other agricultural land use in Japan has also followed the decreasing trend. Between 1969 and 2012 the total agricultural land in Japan decreased from 6.09 million ha to 4.55 million ha (MAFF, 2012).

2.1.7. South Korea

South Korea has a temperate climate with four distinct seasons. Winters are usually long, cold and dry. Summers are very short, hot, and humid. Spring and autumn are pleasant but also short in duration. Seoul's mean temperature in January is -5°C to - 2.5°C and in July the mean temperature is about 22.5°C to 25°C.

The country generally has enough rainfall, rarely it does less than 750 mm of rain fall in any given year; for the most part, rainfall is over 1000 mm. Amounts of precipitation can however vary from year to year. Serious droughts occur about once every eight years. About two-thirds of the annual precipitation occurs between June and September.

South Korea is less vulnerable to typhoons than neighbouring countries. From one to three typhoons can be expected per year. Typhoons usually pass over South Korea in late summer, especially in August and bring torrential rains. Flooding occasionally causes considerable damage.

Precipitation distribution on the Korean Peninsula is mainly affected by orography. The southern coastal and its adjacent mountain regions have the largest amount of annual precipitation which is over 1,500mm. The sheltered upper Amnokgang (Yalu) river basin in the northern region, on the other hand, experiences less than 600mm. Since most of the precipitation is concentrated in the crop growing areas in the south, the water supply for agriculture is normally well met. Even though the annual mean precipitation is more than 1,200mm, however, Korea often experiences drought due to the large fluctuation and variation of precipitation, making the management of water resources difficult.

Korea’s worst recorded drought occurred in 2012. in Korea’s weather observation history. The climate change caused a considerable damage in non-irrigated areas

Despite constant investment in agricultural water development, Korea does not yet have a stable foundation to reliably supply agricultural water in times of drought.

2.1.8. Turkey

Because of Turkey's geographical conditions, one cannot speak about a general overall climate. In Istanbul and around the sea of Marmara the climate is moderate. In winter 4°C and summer 27°C. In Western Turkey there is a mild Mediterranean climate with average temperatures of 9°C in winter and 29°C in summer. On the southern coast the same climate can be found. The climate of the Anatolian Plateau is a steppe climate (there is a great temperature difference between day and night). Rainfall is low and there is more snow. The average temperature is 23°C in summer and -2°C in winter. The climate in the Black Sea area is wet, warm and humid (summer 23°C, winter 7°C). In Eastern Anatolia and South-Eastern Anatolia there is a long hard winter, where year after year snow falls from November until the end of April (the average temperature in winter is -13°C and in summer 17°C).

Turkey receives most of the rainfall in the winter season. In this season, mean temperature usually is below 5°C and there is no too much evaporation. But summer rainfall is very limited and could be not enough to remove water deficit resulted from increased temperature and evaporation.

The Aegean and Mediterranean coasts have cool, rainy winters and hot, moderately dry summers. Annual precipitation in those areas varies from 580 to 1,300 mm, depending on location. The Black Sea coast receives the greatest amount of rainfall. The eastern part of that receives 2,200 mm annually and is the only region of Turkey that receives rainfall throughout the year.

Turkey's diverse regions have different climates because of irregular topography. Taurus Mountains are close to the coast and rain clouds cannot penetrate to the interior part of the country. Rain clouds drop most of their water on the coastal area. As rain clouds pass over the mountains and reach central Anatolia they have no significant capability to produce of rain. In the Eastern region of Anatolia, the elevation of mountains exceeds 2500-3000 m. Northern Black Sea Mountains and Caucasian Mountain hold the rain clouds, and therefore the area is affected by the continental climate with long and very cold winter. Minimum temperatures of -30°C to -38°C are observed in the mountainous areas in the east, and snow may lie on the ground 120 days of the year. Winters are bitterly cold with frequent, heavy snowfall. Villages in the region remain isolated for several days during winter storms.

2.1.9. United Kingdom

The United Kingdom has a temperate climate, with plentiful rainfall all year round. The temperature varies with the seasons but seldom drops below -10°C or rises above 35°C. The prevailing wind is from the southwest, bearing frequent spells of mild and wet weather from the Atlantic Ocean. Eastern parts are most sheltered from this wind and are therefore the driest. Atlantic currents, warmed by the Gulf Stream, bring mild winters, especially in the west, where winters are wet. Summers are warmest in the south east of England, being closest to the European mainland, and coolest in the north. Snowfall can occur in winter and early spring.

Rainfall amounts can vary greatly across the United Kingdom and generally the further west and the higher the elevation, the greater the rainfall. The mountains of Wales, Scotland, the Pennines in

Northern England and the moors of South West England are the wettest parts of the country, and in some of these places as much as 4,577 mm of rain can fall annually, making these locations some of the wettest in Europe. The wettest spot in the United Kingdom is Crib Goch, in Snowdonia, which has averaged 4,473 mm rain a year over the past 30 years. Most rainfall in the United Kingdom comes from North Atlantic depressions which roll into the country throughout the year from the west or southwest and are particularly frequent and intense in the autumn and winter. They can on occasions bring prolonged periods of heavy rain, and flooding is quite common.

Parts of England are surprisingly dry, which is contrary to the stereotypical view—London receives just below 650 millimetres (25.6 in) per annum, which is less than Rome, Sydney, or New York City. In East Anglia it typically rains on about 113 days per year. Most of the south, south-east and East Anglia receive less than 700 mm of rain per year. The English counties of Essex and Cambridgeshire - as well as parts of North Yorkshire, the East Riding of Yorkshire, Suffolk and Norfolk - are amongst the driest in the UK, with an average annual rainfall of around 600 mm. This is due to a mild rainshadow effect, due to mountainous parts of the South West, Wales and Cumbria blocking the moist airflow across the country to the east. In some years rainfall totals in Essex and South Suffolk can be below 450 mm (especially areas around Colchester, Clacton and Ipswich) - less than the average annual rainfall in Jerusalem, Beirut and even some semi-arid parts of the world.

Parts of the United Kingdom have had drought problems in recent years, particularly in 2004-2006. Fires broke out in some areas, even across the normally damp higher ground of north-west England and Wales. The landscape in much of England and east Wales became very parched, even near the coast; water restrictions were in place in some areas.

July 2006 was the hottest month on record for the United Kingdom and much of Europe; however England has had warmer spells of 31 days which did not coincide with a calendar month—in 1976 and 1995. As well as low rainfall, drought problems were made worse by the fact that the driest parts of England also have the highest population density, and therefore highest water consumption. The drought problems ended in the period from October 2006 to January 2007, which had well above average rainfall.

2.1.10. United States of America

The USA is a large country with highly variable geographic and climate conditions.

The western 1/3 of the country is generally made up of high mountains and valleys. The northern part of this area is characterized by significant amounts of snow and rain while the southern part is an arid desert region with little precipitation. Some crops such as grains and pasture hay can be grown in the northern to central regions of this area utilizing natural rainfall. Crops such as alfalfa hay, vegetables and fruits grown in the northern portion of this area and all crops in the southern portion require irrigation utilizing flows in streams originating in the mountains and fed by snowmelt and/or runoff captured in storage reservoirs. Some pumping of groundwater is also utilized as a source of irrigation water.

The central 1/3 of the country is generally made up of a flat prairie with moderate amounts of rain and snow in the northern portions and lesser amounts of precipitation in the southern portion. Generally, crops such as wheat and corn can be grown without the aid of irrigation in this region of the country but many growers utilize irrigation for protection against periods of drought and also to increase production. Irrigation sources include surface water from streams and pumping of groundwater.

The eastern 1/3 of the country is characterized by rolling hills with moderate amounts of rain and snow in the northern part and moderate amounts of precipitation in the southern part. Generally, crops grown in this region do not require irrigation, even during the dry season. Pumping of groundwater is the main source of any irrigation water utilize in this region.

The 2007 United States Department of Agricultural Census shows that there were 2.2 million farms covering 922 million acres (3,730,000 sq, km.) of land. Of those 922 million acres of farmland, only 56.6 million acres were irrigated. Therefore, over 865 million acres of farmland depend upon natural rainfall for crop production.

2.2. Summary of methods to increase rainfall effectiveness

Methods in use in the various countries to increase rainfall effectiveness can be summarised as follows:

2.2.1. Australia

- In low intensity grazing areas, moving stock and increasing or decreasing stock numbers;
- Fallowing in dryland cropping areas;
- In both dryland and irrigated areas, seeking improved plant varieties that are able to make the best use of available moisture;
- In southern irrigated pasture areas, a move away from perennial summer pastures to annual pastures which make better use of spring and autumn rainfall;
- More sophisticated measurement of soil moisture;
- Use of precisely applied drip or perforated tape irrigation;
- Improved weather forecasting to enable managers of large gravity irrigation systems to reduce flows in anticipation of reduced orders from irrigators;
- In pumped irrigation districts, progressive replacement of channels with pipelines;
- In large gravity irrigation districts the introduction of “total channel control”.

2.2.2. Chinese Taipei

- Mechanisms to manage drought;
- Finding new water resources.

2.2.3. India

- Linking of large and small irrigation systems;
- Channel lining and pipelining;
- Improved irrigation techniques.

2.2.4. Iran

- Improved rainfall forecasting;
- Conjunctive use of surface water and groundwater;
- Operational programs to apportion available water;
- water loss reduction projects;
- using energy price to control pumping;
- Publicity programs to support drought management measures;
- Encouraging water saving measures by farmers.

2.2.5. Italy

2.2.6. Japan

- Drought management (ref ja1) appears to concentrate on equitable sharing of the available water.

2.2.7. South Korea

- More comprehensive planning for drought;
- Replacing stored water with run-of-river flows and wastewater;
- Replacing stored surface water with groundwater;
- Infrastructure improvement.

2.2.8. Turkey

- Construction of small ponds;
- Transition to modern irrigation techniques;
- Drought management plans;
- Drought monitoring and early warning systems;
- Reuse of wastewaters for irrigation;
- Construction of Groundwater dams;
- Research on determination of evapotranspiration;
- Studies to determine the effects of climate change to water resources;
- Enhancing the monitoring systems for surface water and groundwater uses.

2.2.9. United Kingdom

2.2.10. United States of America

- Better use of weather forecasting to determine water needs in irrigated areas;
- Use of soil moisture measurement technology in conjunction with weather forecasting to schedule irrigation deliveries;
- Increase soil holding capacity of soils through introduction of additional organic material, modified tillage methods, etc.;
- Moving cattle and other grazing animals from one pasture to another to take advantage of forage development based on varying soil and moisture conditions;
- Fallowing areas to allow recovery of soil moisture content;
- Increase the soil infiltration rate through improved tillage methods;
- Use tillage methods that create small pockets that hold rainwater to increase infiltration;
- Use of conservation tillage that keeps approximately 30% of the soil surface covered with plant residue from the previous crop;
- Using tilling methods to loosen compacted soils;
- Eliminating chemical restrictions to root growth such as liming acid subsoils;
- Crop management to take advantage of crop needs at various stages of growth;
- Improved methods of delivery and use of irrigation water to maximize the conjunctive use of precipitation and irrigation water;
- Comprehensive drought monitoring service.

3. Increasing rainfall effectiveness

This section discusses in more detail the methods listed in the above section.

3.1. Australia

3.1.1. Manipulating stock location and numbers

Stock numbers in Australia rise and fall with seasonal conditions. Droughts can last for many years (Ref au2) and it has been estimated that more than 100 million sheep died in the severe droughts that have affected the Australian pastoral industry over a century. Long droughts can decimate stock numbers and severely degrade the rangelands.

Severe droughts mean that stock numbers reduce, either as a management measure or simply because they starve. However droughts can be managed to some extent.

A traditional technique is to make use of the "long paddock"; droving stock slowly along road reserves and letting them consume the feed on the reserve. Many road reserves are three chains (about 30 metres) or five chains (about 50 metres) wide and the actual roadway occupies only a small part of the reserve.

Another form of managing in droughts is to move stock under agistment (i.e. an arrangement with the owner of a supply of feed to take in stock and feed them for a period). Under Australian conditions there may be drought in quite a wide geographic area, so stock may have to be moved hundreds of kilometres, either by rail, truck or by droving them on foot. A disadvantage of wide scale movements of this sort is that it can spread disease in the stock.

Management techniques that are becoming increasingly available include:

- Degradation alerts based on seasonal forecasting, stock number data and simulated predictions of pasture production;
- Analysis of the impacts of climate variability; and
- Long term records that enable analysis of what grazing management decisions were successful and which, with the benefit of hindsight, were mistakes.

3.1.2. Fallowing

There is nothing new in this – the practice is centuries old. Fallowing refers to land that is tilled but left un-seeded during a growing season. The intent is to conserve soil moisture (and possibly nutrients) so that the subsequent crop can use both the soil moisture stored in the fallow season and the rain / soil moisture received in the growing season.

Fallowing is extensively practised in the drier grain growing areas in southern Australia

3.1.3. Improved plant varieties

There has been continuing research for many decades into developing more drought-resistant plant varieties to suit Australian conditions. The CSIRO website (ref au3) is a good starting point to find relevant scientific papers

3.1.4. Perennial to annual pastures

In southern irrigated pasture areas, a trend has been evident to move away from perennial summer pastures, which require continual irrigation throughout the dry summer, to annual pastures which make better use of spring and autumn rainfall and dry off during summer

A study in northern Victoria (ref au4) found that annual pastures produced 60-80% of the dry matter of perennial pastures while using only 40-60% as much irrigation water.

3.1.5. Measurement of soil moisture

Measurement of soil moisture is important both in dryland and irrigated agriculture. In dryland and irrigated cropping areas, together with long range weather forecasts, knowledge of the soil moisture status assists decisions on whether to plant a crop or not. In more intensively irrigated areas soil moisture is important for scheduling irrigations and in assessing the effect of rainfall that can extend the periods between irrigations.

Ref au5 provides a summary of techniques available in Australia for measurement of soil moisture.

3.1.6. Root zone irrigation

Over several decades, irrigation in horticultural areas has progressively moved from furrows to high level sprinklers to low level sprinklers to drip and perforated tape irrigation that waters only the root zone of the plants. Each change has made more effective use of the water supplied from surface dams or aquifers to the irrigation property. However salt in the soil can build up if drip or perforated tape irrigation is used, and occasional rainfall is necessary to provide a leaching fraction. If the rain does not occur, a leaching irrigation may eventually be necessary.

These more efficient ways of applying irrigation water thus depend in part on rainfall if use of irrigation water is to be minimised, but the timing of the rainfall can vary widely.

3.1.7. Weather forecasting

Improved medium term weather forecasting is important both to farmers and to operators of large irrigation systems.

As described above, it can assist farmers in decisions about managing stock numbers on dryland grazing country, in deciding whether or not to plant a crop in both dryland and irrigated areas, and in conserving irrigation water.

It is also of assistance in managing large irrigation systems in the following ways:

- Supply to many surface water irrigation systems is sourced from large on-stream storages that are managed primarily for water supply but also mitigate floods. The balance between these two benefits – essentially deciding when to “pre-release” water in a way that maximises flood mitigation while still allowing the storage to fill at the end of the wet season – is assisted by knowledge of rain to be expected in the coming weeks or months. Better weather forecasting can reduce the incidence of failing to fill storages because of earlier pre-releases and so maximise water available for irrigation.
- Surface water supply systems can be large, and often make use of natural rivers as supply routes. For example the major storages on the Murray River are about 2000 km by river from the most downstream irrigation areas they supply. It takes about 30 days for a change in flow at the upper end to be reflected at the lower end. There are limited opportunities to re-regulate water along the way. Clearly a good knowledge of weather conditions and rainfall for the next month would be of great assistance in regulating the river flow and minimising “rain rejections” of water that turns out to be not required by irrigators and simply passes down the river. Such water may or may not have environmental value in the lower reaches of the river, but it is lost to irrigators.

The accuracy of medium term weather forecasts has improved markedly over the past decade or two.

3.1.8. Replacement of channels with pipelines

This obviously reduces losses by seepage and evaporation, but it also improves control of water in the distribution system, reducing outfalls back to the river. These outfalls may or may not be able to be re-used.

3.1.9. Total channel control

"Total channel control" refers to a system that can be applied to large gravity channel distribution systems. It involves the installation of automatic control gates, communications networks and control and management software on existing systems. It is a product developed and marketed by Rubicon Systems Australia P/L that is claimed to enable water to be supplied close to "on demand", producing many of the benefits of pipelining in large gravity systems with earthen channels that cannot economically be replaced with physical pipelines.

Ref au6 describes a pilot project carried out in Northern Victoria in 2004. Since then the concept has become more accepted in Australia and other countries.

3.2. Chinese Taipei

3.2.1. Mechanisms to manage drought

Ref ct1, is concerned with measures to manage drought. The obvious method is to increase water storage, but it this is difficult because of geographic constraints and lack of available sites because of the high population density.

3.2.2. Finding new water resources

Another solution to solve the water scarcity is on the finding of new water resources. Some projects intended to create new water resources are under investigation. Examples (ref ct2) are desalination, reuse of industrial water, rainwater cistern, modification of planting process, etc.

3.3. India

3.3.1. Linking of large and small irrigation systems

The state government of Karnataka in southern India has initiated a novel programme of rehabilitation of tanks by desilting and networking of irrigation systems between major and minor irrigation reservoirs. Results have been (ref in1):

- Reduced effects of drought in previously drought-prone isolated systems;
- Reduced waterlogging in major irrigation sytems that were previously irrigating inefficiently;
- Increased recharge of groundwater in in the low rainfall, mainly rain fed areas;
- Economic improvements in the mainly rainfed areas, and reduced migration away from them;
- Improved micro climate in the rain fed areas; and
- Minimised flood damage in some areas

3.3.2. Channel lining and pipelining

The above networking was accompanied by conventional methods of reducing losses in the major irrigation areas, such as lining of major channels and pipelining of smaller ones.

3.3.3. Improved irrigation techniques

A further element of the overall project was the adoption of improved irrigation techniques such as sprinkler and drip irrigation.

3.4. Iran

3.4.1. Improved rainfall forecasting

Seasonal and long term meteorological models are used to forecast precipitation and inflows to reservoirs, based on different scenarios. The forecasts are used to prepare operation programs and in day to day operation of irrigation systems to maximise the effectiveness of rainfall

3.4.2. Conjunctive use of surface water and groundwater

Scarcity of surface water for much of the time, and its tendency to appear as flash flood flows during occasional periods of rain, has historically forced Iranian agriculture to exploit groundwater resources, traditionally by the gravitational method of combining wells and a sloping gallery internationally known as the Kariz or Qanat. Construction of these systems was a tedious task requiring large amounts of manpower, and they could take generations to build. Therefore a village, or sometimes a number of villages would share the right to water from the same Qanat and participate in its maintenance.

In arid areas in which groundwater is scarce and mostly brackish, it is used primarily during periods of surface water scarcity for orchard irrigation and then other crops, while the late fall, winter and early spring flash floods are used for flood irrigation of the orchards, cropped and fallow lands, and for salt leaching of the soil, saving moisture for spring cropping, and other opportunistic irrigation.

At present, with access to pumps and electricity, deep groundwater is being extracted and this can endanger groundwater quality and the existence of Qanats.

3.4.3. Operational programs to apportion available water

Operating plans for the various water systems are routinely prepared at the beginning of the water year. These programs prioritize supply of water for drinking, sanitary purposes, sustaining orchards and permanent crops, supply to more valuable crops, etc.

3.4.4. Water loss reduction projects

These include:-

- construction of pipe networks for agricultural and domestic water use;
- public information and extension services and socio-cultural capacity building for efficient water use;
- equipping water wells with volumetric water meters;
- equipping irrigation networks with water control and measuring equipment; and
- water pricing to discourage wasteful use which incurs high losses.

3.4.5. using energy price to control pumping

Pricing of electrical energy can be used as a mechanism to discourage pumping from surface and groundwater, but especially from deep groundwater.

3.4.6. Publicity programs to support drought management measures

Public relations officers of different institutions inform the public about drought, how to cope with it, and prevention of wasteful use of water. The aim is to avoid any sort of social crisis.

3.4.7. Encouraging water saving measures by farmers

Mechanisms that farmers can be encouraged to use include:

- Night irrigation to reduce evaporation;
- Careful water scheduling;
- Encouraging the use of pressurised irrigation systems and lining of canals;
- Changing annual cropping patterns to avoid high water consuming crops; and
- Preventing spring and summer cropping (as the second crop).

3.5. Italy

3.6. Japan

Despite its high rainfall, Japan's agriculture is largely supplemented by irrigation, because it concentrates on rice production. Rights to extract water from streams are well developed. Shortages during drought are resolved via Drought Conciliation Councils, which share the available water between the various holders of rights. The need for these Committees is increasing at least partly because of higher temperatures and lower precipitation caused by climate change.

3.7. South Korea

3.7.1. More comprehensive planning for drought.

Korea's spring drought in 2012 led to water shortage in 7,216ha of unplanted area and 8,920ha of planted paddy. At that time, Korea established countermeasures to secure water for agricultural use and completed most of rice planting. But, 6,452ha of upland field crops were considerably damaged because the dry fields had insufficient irrigation facilities for emergency supplementary irrigation.

Improvement is needed to the operation system of disaster and safety countermeasures. The Korean government has an integrated disaster and safety countermeasures for damages from drought, storm and flood, but the Korean Rural Community Corporation (KRC) does not.

Korea also needs to improve and expand a drought information system in the agricultural field, by building an integrated water resource management system.

3.7.2. Replacing stored water with run-of-river flows and wastewater.

In 2012 drought damage was reduced by, as far as possible, using run-of-river flows rather than stoted surface water for irrigation. Further savings were made by substituting wastewater for stored surface water.

3.7.3. Replacing stored surface water with groundwater.

There is scope to use groundwater conjunctively with surface water, drawing on groundwater primarily in times of shortage of surface water.

3.7.4. Infrastructure improvement.

Outdated irrigation facilities and earth canals are matters to solve. Many irrigation facilities in Korea are more than 30 years. 60% of all irrigation and drainage canals in Korea also are prone to water wastage because they are earthen.

3.8. Turkey

3.8.1. Construction of small ponds

Turkey started to construct small dams to store waters in rural areas. Small dams increase reservoir capacity for water. Small dams decreases the groundwater uses and ensure groundwater extraction in safe yield.

3.8.2. Transition to modern irrigation techniques

In recent years, Turkey has pursued water savings in the conveyance of water and lessening the on-farm water losses. Pressurized pipe systems, sprinkler and drip irrigation methods were utilized after 2003. A project is being implemented for rehabilitation of irrigation systems with O&M responsibilities being transferred to water user organizations. A basic principle of the Project is that water users bear part of the costs.

3.8.3. Drought management plans

Drought management plans are key tools to cope with drought. Plans consist of the determination of drought, responsible institutions, responsibilities and actions. The main aim of the drought management plan is to lessen the negative impacts of drought in different sectors (Agriculture, domestic water supply, energy etc.)

3.8.4. Drought monitoring and early warning systems

Droughts have some important early signals like decrease in rainfall, snow, groundwater levels and surface water storages. Monitoring of these parameters and using drought indicators (SPI, palmer drought index) are very common methods for early warning. In addition to this, large scale atmospheric circulations (North Atlantic Oscilation) are related to the drought conditions of Southern Europe and Turkey.

3.8.5. Reuse of wastewaters for irrigation

Re-use of wastewater is another water supply possibility and also some studies to use return flows from irrigation for irrigation again.

3.8.6. Construction of Groundwater dams

Storing water under the ground decreases evaporation loses and increases water storage capacity. In recent years, Turkey started to construct groundwater dams in the semi-arid Middle Anatolia Region.

3.8.7. Research on determination of evapotranspiration

The main water loss from the surface is evapotranspiration. In Turkey, annual mean precipitation is 643 mm, which corresponds to 510 billion m3 of annual water volume in the country. A volume of 274 billion m3 water evaporates from water bodies and soil. It is important to determine evapotranspiration precisely to take necessary precautions to lessen it.

3.8.8. Studies to determine the effects of climate change to water resources

Climate change projections show an increase in temperatures all over the Turkey and a decrease in precipitation in some parts of the country. There are potential effects of climate change on drought duration and severity.

3.8.9. Enhancing the monitoring systems for surface water and groundwater uses

The first step to control water uses is monitoring. By monitoring water resources, implementation of allocation strategies, water pricing policies can be implemented. Groundwater Monitoring System Regulation came into effect in 2011.

3.8.10. Rising awareness of water users

The main water user sector is agriculture. In Turkey 73% of water use is for irrigation. For this reason, training of farmers is of crucial importance.

3.9. United Kingdom

3.10. United States of America

3.10.1. Weather forecasting

Weather forecasting is used to determine water needs in irrigated areas in advance. Improved and longer range forecasting adds value to this technique.

3.10.2. Soil moisture measurement

Soil moisture measurement technology in conjunction with weather forecasting to schedule irrigation deliveries assures soil moisture holding capacity is available when rainfall is anticipated (creates space for the rainfall to be fully utilized).

3.10.3. Modified tillage

Introduction of additional organic material, modified tillage methods, etc. Increase the water holding capacity of soils

3.10.4. Movement of stock

Moving cattle and other grazing animals from one pasture to another takes advantage of forage development based on varying soil and moisture conditions.

3.10.5. Fallowing

Fallowing is a long established technique to allow recovery of soil moisture content.

3.10.6. Increasing soil infiltration

Improved tillage methods increase soil infiltration rates as well as the water holding capacity of the soil.

3.10.7. Tillage to hold surface water

Tillage methods that create small pockets that hold rainwater also increase infiltration.

3.10.8. Conservation tillage

Conservation tillage keeps approximately 30% of the soil surface covered with plant residue from the previous crop. Residues increase rainfall infiltration by acting as small barriers that slow water movement down slopes. Residues on the on the surface also absorb the force of raindrops that fall to the soil, reducing the packing effect of raindrop impact on the soil surface. Residues on the surface also reduces soil water evaporation by acting as a physical barrier to water vapour movement from the soil to the air as well as keeping the soils cooler and thereby reducing the energy level at the soil surface.

3.10.9. Loosening compacted soils

Tillage methods that loosen compacted soils increase the volume of soil that roots have to grow in.

3.10.10. Eliminating chemical restrictions

Chemical restrictions to root growth can be reduced or eliminated by methods such as liming acid subsoils.

3.10.11. Crop management at different growth stages

Crop management methods that take advantage of crop needs at various stages of growth are used to maximize the use of available water supplies. For example, maximizing early season vegetative growth in forage crops to take advantage of available water is a good practice while encouraging early vegetative growth of grain crops can have a detrimental effect on the yield of that crop when water is not as available later in the season when the grain matures.

3.10.12. Improved irrigation delivery

Improved methods of delivery and use of irrigation water can maximize the conjunctive use of precipitation and irrigation water. This involves the use of new technology in water measurement, water flow control and water conservation.

3.10.13. Comprehensive drought monitoring service

A comprehensive nation wide drought monitoring service is produced, updated each week (Ref us2)

4. Documentation of practices

4.1. Australia

As shown in the various references, there is plenty of documentation available about the various techniques described above.

As always, there can be a long gap between the development of a technique by researchers and its adoption by farmers and system operators. This can be for various reasons including lack of education of the rural population, availability of funds, economic efficiency compared with technical efficiency etc.

In Australia the farming population is relatively well educated and becoming more so. Despite that, there will always be innovators who are willing to try new ideas first. If the idea is seen to work it will be taken up relatively rapidly by mainstream farmers, subject always to economic pressures. There will also always be a few conservatives who are slow to adopt improvements.

In Australia, until about 2002 many techniques for maximising the effective use of both rainfall and irrigation water were not widely used, simply because there was no economic imperative. The capital cost of more efficient irrigation systems or more intensive management of dryland farming was less than the cost of extra irrigation water or continuing with lower input management arrangements.

That has changed in the past decade, largely due to a series of drought years which may well be an indication of more permanent climate change. The result is that water-efficient management is becoming more economically attractive simply because of a lack of water. Despite that, the adoption of new techniques can still be inhibited by lack of capital, which in many cases has been cause by the same period of drought.

4.2. Chinese Taipei

The booklet cited as ref ct1 is good background and describes in detail the bureaucratic and institutional processes of drought management in Taiwan. However it does not cover technical responses to drought management.

4.3. India

4.4. Iran

Water allocation plans are prepared by provincial committees and reviewed and approved at national level. This process is very public and well documented.

4.5. Italy

4.6. Japan
Reference ja1 cites several further references on drought management in Japan.

4.7. South Korea
Reference sk1 cites several further references on drought management in South Korea

4.8. Turkey
Rainwater harvesting was in common during the Bizantine period of Anatolia. There are lots of cisterns all around the Anatolia. Some of them are still in use, others are tourist attractions.

Documentation of practices includes:

- Basin master plans;
- Basin management plans;
- Drought Management plans;
- Groundwater Dams (in Turkish);
- Preservation of historical water structures.

4.9. United Kingdom

4.10. United States of America
Rainfall harvesting in the United States has not been as aggressively pursued as in other countries throughout the world. The documentation of rainfall harvesting for municipal or domestic use is rapidly increasing in the USA as demand for water in these areas increases.

Documentation of rainfall harvesting in the USA for agricultural purposes is plentiful as it relates to modification of tilling methods to make better use of precipitation. Documentation of rainfall harvesting by collecting runoff of buildings, etc. for agricultural uses is essentially non-existent except for some documentation of using this method to obtain water for washing of produce, cleaning of equipment and facilities, etc. This can be explained in part to the fact that many producing farms in the USA are very large operations and require large quantities of water to operate.

As competing demands for water among the environment, agriculture, recreation, domestic and industrial arenas increase, the need to utilize all sources of water to their maximum extend will also grow. This will also bring about a need to increase research and educational opportunities in the rainfall harvesting area.

5. New practices and experiences

5.1. Australia

1.1.1. Cloud seeding

Snowy Hydro

Snowy Hydro Ltd is the operator of the Snowy Mountains Hydro-electric scheme, and its main purpose is to generate hydro-electricity from the Scheme, which covers much of the Australian Alps. Snowy Hydro has been carrying out a detailed cloud seeding trial since 2004. A mid-term review of the trial (Ref 7) by the Natural Resources Commission NSW found that:

- The trial was being conducted to a high scientific standard;
- There was no evidence of adverse environmental impacts; and

- There was evidence that cloud seeding increased snowfall in the target area under defined weather and operating conditions.

Hydro Tasmania
Hydro Tasmania operates many hydro-electric projects in the State of Tasmania. It has been involved (Ref 8) in both experimental and operational cloud seeding since 1964. It conducted three successful experiments on cloud seeding:

- Stage I: 1964-1971. This was an alternate year experiment providing randomisation on a seed/no seed 1:1 ratio in conjunction with CSIRO. The target area was the Central Plateau and silver iodide was used as the seeding agent.
- Stage II: 1979-1983. The experiment used a ratio of suitable seeded/unseeded days at 2:1 to provide randomisation and was also conducted in conjunction with CSIRO. Silver iodide was used as the seeding agent.
- Stage III: 1992-1994. This experiment was very similar to Stage II except that dry ice was used as a seeding agent and the work was completed by Hydro Tasmania alone.

Hydro Tasmania now cloud seeds on a regular operational basis.

1.1.2. Cloud and fog harvesting and trapping
There appears to be no Australian experience in this area.

5.2. Chinese Taipei
There appears to be no Taiwanese experience in this area.

5.3. India

5.4. Iran
Cloud seeding – Iran appears to have a serious interest in cloud seeding – see ref 2

Fog harvesting – again Iran appears to have an interest – Ref 3 concluded that the south of Iran had the potential to harvest fog and moisture from the humid atmosphere for 160 – 360 days per year.

5.5. Italy

5.6. Japan

5.7. South Korea

5.8. Turkey
Early warning of droughts are studied by Turkish researchers in the context of the relation between large scale atmospheric circulation and droughts. See references.

5.9. United Kingdom

5.10. United States of America
Cloud seeding is the most extensive method used in the United States of America to increase precipitation. Cloud seeding is the deliberate treatment of certain clouds or cloud systems with the

intent of affecting the precipitation process(s) within the clouds. Cloud seeding can be used to increase precipitation, fog dispersal for improved visibility and hail suppression. The most common use of cloud seeding is to increase precipitation. Cloud seeding projects in the USA began in the late 1940s. Presently there are over 60 active cloud seeding projects in the USA. The USA does not pursue this method of maximizing the effective precipitation as extensively as other countries of the world. However it is still a very important aspect of managing water resources. The effectiveness of this process is somewhat questionable but researchers estimate that precipitation in treated areas can be increased by more than 10%.

It has been estimated that present cloud seeding operations throughout the Sierra Nevada mountains in the States of California and Nevada produce an additional 300,000 to 400,000 acre-feet of water annually. Another 300,000 to 400,000 acre-feet per year may be available from these same mountains.

6. Other contributions

Two papers originating from countries other than those included in the main parts of this paper have been received.

- Reference ot1, from France, describes field trials to estimate the impact of different drip line distances at the experimental site using a new optimal Subsurface drip irrigation (SDI) management framework. Using Hydrus-2D, optimal irrigation control functions for a uniform distribution of the irrigation water while minimizing deep percolation were determined. A simulation based approach was applied to optimize the intra-seasonal adaptive deficit irrigation schedule.
- Reference ot2, from Indonesia, describes the development of a hydrological drought index for Indonesia, using the indicator of traditional pasten, or its modern derivative indicating the ratio between water supplied available and the corresponding water demand in an irrigation system.

7. References

7.1. Australia

au1	Northern Land and Water Taskforce. December 2009. *Sustainable development of Northern Australia*. ISBN 978-1-921095-94-8
au2	Queensland Dept of Natural Resources, Mines and Energy May 2004. *Pasture degradation and recovery in Australia's Rangelands.* ISBN 1 920920 55 2
au3	CSIRO website: Home > Food and Agriculture > Farm management > Drought and farming
au4	A Lawson, K Greenwood and K Kelly 2007. *Production and water use of irrigated pastures in northern Victoria*. Victorian Dept of Primary Industries, Kyabram.
au5	ICT International website – Home > Application notes > Soil moisture measurement implementation.
au6	Dept Sustainability & Environment, Goulburn-Murray Water and Rubicon Systems Aust 2004. *Total Channel Control System Pilot on CG2 Channel, Tatura*
au7	Natural Resources Commission NSW 2010. *Mid term Review of the Snowy Mountains Cloud Seeding Trial.*
au8	Hydro Tasmania website – Home > Water > Cloud seeding

7.2. Chinese Taipei

ct1	Chinese Taipei Committee, ICID, August 2011. *Drought Disaster Preparedness and Relief Operations of the Irrigation Associations in Taiwan*.
ct2	Jan Ming-Young and Cheng Chang-Chi, ICID drought workshop Oct 2013 *Drought related studies conducted in Taiwan beyond 1990's*

7.3. India

in1	Ramana Gowda, P., Krishnamurthy, N., Suresh Naik, K.P. and Asha, L., ICID Drought Workshop Oct 2013 *Rehabilitation of Irrigation Systems - Networking of Irrigation Systems to Mitigate Drought for Sustained Agriculture Production in Karnataka, India*

7.4. Iran

ir1	Mohammed Sadegh Jafari, October 2011. *Iranian Experience in Coping with Water scarcity.*
ir2	Radiozamaneh.com. *Cloud seeding in Iran; a possible dream or a distant illusion?*
ir3	Rahman Davtalab and Aliresa Salamat, ICID Conference Oct 2011 *Water harvesting from fog and air humidity in the warm and coastal regions in the south of Iran.*

7.5. Italy

7.6. Japan

ja1	Takanori NAGANO and Akihiko KOTERA, ICID Drought workshop Oct 2013 *Recent Trends of Drought Conciliation and Agricultural Water Use in Japan*

7.7. South Korea

sk1	Chang Jo Oh, ICID Drought workshop Oct 2013 *Korea's Drought Status and a Case Study for Drought Overcome in 2012*

7.8. Turkey

tu1	Kadıoglu,M,2008, Drought Risk Management, JICA Turkish Office Publications.
tu2	Sırdas, S.and Sen, Z., 2003, Meteorological Drought Modelling and Application to Turkey, ITU Journal.
tu3	Turkes, M and Tatli,H. 2009, Use of the standardized precipitation index(SPI) and modified SPI for shaping the drought probabilities over Turkey. International Journal of Climatology.
tu4	Turkes,M and Erlat, E. 2009 Winter mean temperature variability in Turkey associated with North Atlantic Oscillation. Meteorology and Atmospheric Physics
tu5	Turkes, M, Koc,t and Sırdas F, 2009 Spatiotemporal variability of precipitation total series over Turkey. International Journal of Climatology
tu6	Sen,Z. 1980,Statistical Analysis of Hydrologic Critical Drought,Journal of Hydraulic Division
tu7	Sırdas,S and Sen, Z., 2003 Spatio-temporal Drought Analysis in the Trakya Region , Turkey, Hydrological Science Journal.
tu8	Aksu, H., Uçar,İ,2013 Drougt Assessment of Ankara, First World Irrigation Forum.
tu9	Apaydın, A, 2014 Groundwater Dams , State Hydraulic Works of Turkey (in Turkish)
tu10	BİLDİRİCİ,M. 1994, Anatolian Historical Water Structures, Conference on Development of Water and Land Resources (in Turkish)
tu11	Büyükyıldırım, G., 1994 Historical Water Structures in Antalya Region, DSI (in Turkish)

7.9. United Kingdom

7.10. United States of America

us1	Frank Dimick / USCID, April 2012. *United States of America Country Paper – Rainfall harvesting and management for sustainable agriculture in water stressed / scarce regions.*
us2	Drought monitoring service http://droughtmonitor.ual.edu

7.11. Other

ot1	Walser, S., Schütze, N., Fahle, M. and Ruelle, P. *Optimal irrigation scheduling and irrigation control to increase water productivity and profit in subsurface drip irrigated agriculture.*
ot2	Waluyo Hatmoko, R. Wahyudi Triweko, and Iwan K. Hadihardaja *Hydrological Drought Index Based on Traditional Pasten System*