JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

THE MINISTRY OF AGRICULTURE AND FISHERIES,
THE GOVERNMENT OF THE SULTANATE OF OMAN

THE STUDY ON AGRICULTURAL DEVELOPMENT PROJECT IN THE NEJD REGION

(Phase II Study, Work III)

FINAL REPORT

VOLUME I

MAIN REPORT

MAY, 1997

PACIFIC CONSULTANTS INTERNATIONAL

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RO : Rial Omani

PREFACE

In response to the request from the Government of the Sultanate of Oman, the Government of Japan decided to resume a study on Agricultural Development Project in the Nejd Region and entrusted the study to Japan International Cooperation Agency (JICA).

JICA sent a study team headed by Mr. Seishiro Suzuki, Pacific Consultants International, Japan to Oman from April 1995 to November 1996.

The team held discussions with the officials concerned of the Government of the Sultanate of Oman and conducted field surveys at both of Nejd Agricultural Research Station and the study area. After the team returned to Japan, further studies were made and the present report was prepared.

I hope that this report will contribute to the promotion of the project and to the enhancement of friendly relations between the two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the Sultanate of Oman for their close cooperation extended to the study team.

May 1997

Kimio Fujita

Kimio Fujita
President,
Japan International Cooperation Agency

May , 1997

Mr. Kimio FUJITA
President
Japan International Cooperation Agency
Tokyo, Japan

Letter of Transmittal

Dear Sir,

We are pleased to submit hereby the final report on the Study on Agricultural Development Project in the Nejd Region (Phase II, Work III). This report incorporates the advice and suggestion of the authorities concerned of the Government of Japan and Japan International Cooperation Agency in the formulation of the above mentioned study. The comments made by the Ministry of Agriculture and Fisheries of the Government of the Sultanate of Oman during discussions which were held in the Sultanate of Oman are also clarified in the final report.

The study result showed that the present ground water use in the study area exceeds its sustainable potential. In case the present free abstractions are maintained, the draw down of the ground water head in the study area would be drastically more.

The direction for the agricultural development for the study area was to feed back to the original Phased Development Concept, which was proposed in the Phase I Study, to understand more details of ground water resources while enforcing research, training and extension activities of the Nejd Agricultural Research Station (NARS). A plan of New Pilot Farm net work was shown as an example to correct the present development condition and to expand regional monitoring system in the region.

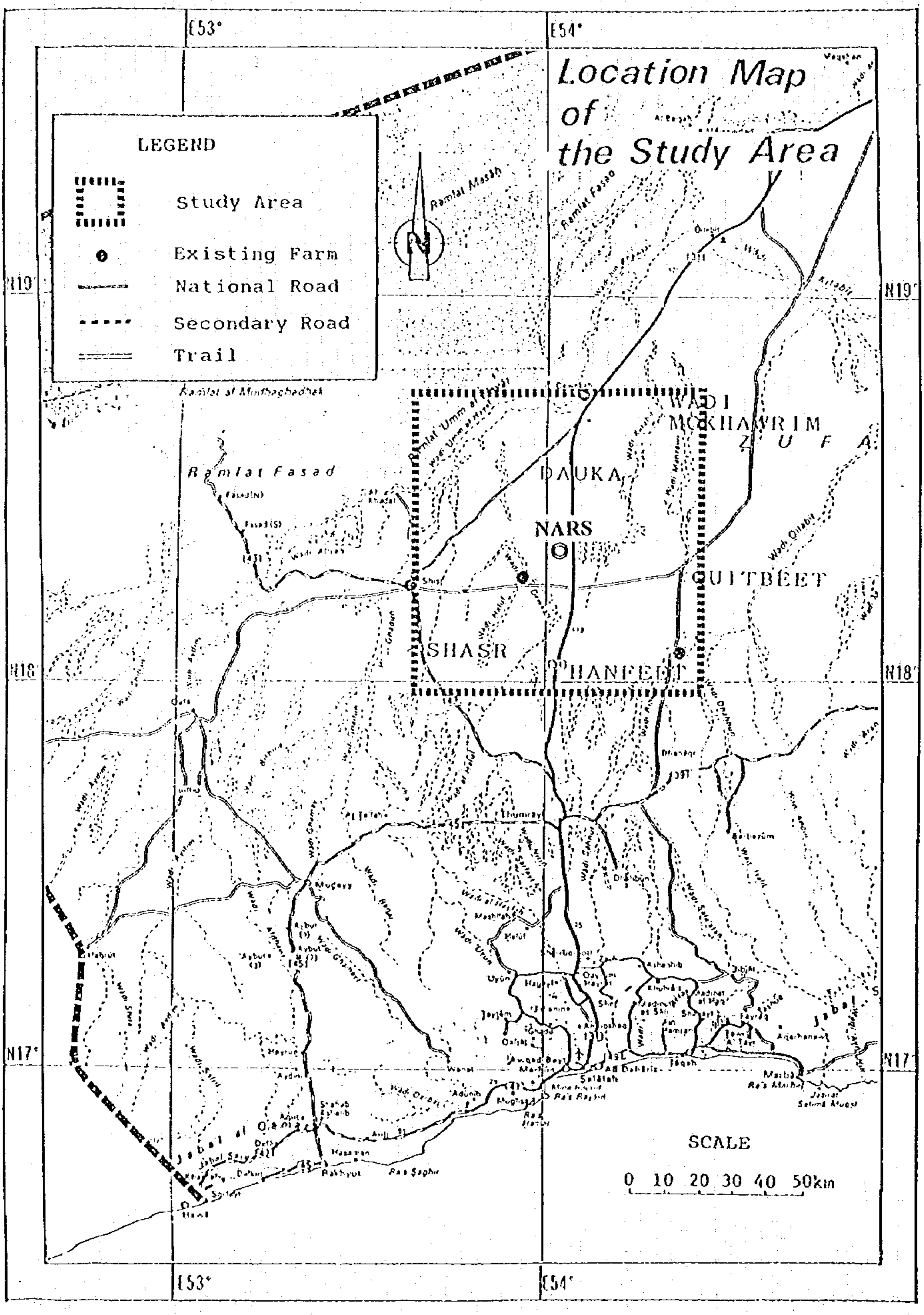
The report consists of two volumes, namely Volume One; Main Report inclusive of Executive Summary and Volume Two; Appendices.

We wish to take this opportunity to express our sincere gratitude to the related authorities of Japan International Cooperation Agency and the Government of Japan for their effective advice and suggestion for the study. We would like to express our heartiest appreciation to the relevant officials of the Ministry of Agriculture and Fisheries and the other agencies of the Government of Sultanate of Oman who are listed in Annex of the Main Report for their close cooperation and warm assistance extended to the study team during its works in Oman.

Very Truly Yours,

S. Suzuki

Seishiro SUZUKI
Team Leader,
The Study on Agricultural Development
in the Nejd Region



Location Map of the Study Area
LEGEND
Study Area
Existing Farm
National Road
Secondary Road
Trail
E53°
E54°
N19°
N18°
N17°
WADI MOKHAWRIM
ZUFA
DAUKA
NARS
QUITBEET
SHASR
HANFEET
Ramlat Fasad
SCALE
0 10 20 30 40 50km

SULTANATE OF OMAN
THE STUDY ON AGRICULTURAL DEVELOPMENT PROJECT
IN THE NEJD REGION (PHASE-II, WORK-III)

FINAL REPORT

EXECUTIVE SUMMARY

Conclusions and Recommendations

(1) Conclusions

The main development policies of the Government of the Sultanate of Oman in the agricultural sector are summarized as 1) to develop sustainable agriculture, 2) to increase domestic production, 3) to achieve self-sufficiency in food for import substitution, 4) to create employment opportunities and 5) to conserve natural resources and the environment. The specific development objectives of the Agricultural Development Project in the Nejd Region are recognized in those governmental development policies, as well as with the physical and socio-economic conditions of the Study Area, as shown below:

1. Expansion of agricultural production area through optimum exploitation of water resources to attain food to self-sufficiency.
2. Creation of new employment source for local Omanis and improvement of agricultural labour force.
3. Strengthening and modernisation of institutional services for agricultural experimentation and extension activities.

A Pilot Farm Plan was proposed as an actual approach on the same line of the Phased Agricultural Development Concept which was developed at the end of the Phase I Study, whose objectives were to clarify the technical constraints through agricultural experiments and to predict the development potentiality of the groundwater resources. The name of the Pilot Farm was later changed as Nejd Agricultural Research Station (NARS) and there were some modifications in the objectives of the original pilot farm concept, as much importance is given to scientific research rather than experimental trials.

As the overall evaluation in the end of the First Phase of the development plan, land resource and agricultural research have been able to achieve their purposes almost all except some aspects, through the activities of two years monitoring survey at NARS.

Besides, number of centre pivots and cultivated area with irrigation in the Study Area has been increased rapidly during the last two or three years. Presently more than 800ha has been under irrigation and adding constructing and planning areas, the total developed area can be estimated as more than 1,000ha.

Significant groundwater drawdowns have been occurred over the past two years. Most drawdown is noticed at Hanfeet where irrigation using center pivots has recently expanded drastically. It was said that usually over 85% of drawdown occurs in the first year of operation and only minor reductions in drawdown occur in the following years. However, actual phenomena of wells in the Nejd region seems to be clearly different from this trend.

It is clear from the results of the Phase-I Study and the field survey of the Phase-II Study that the water resources is the largest restrictive factor against agricultural development and development pace and scale will be decided by the development potential of the groundwater conditions.

It is clear that the hydrogeology of the region is not well understood and more assessment work is required for the better understanding of the aquifer characteristics and to evaluate the sustainable yield. Consequently, before shifting to the Second Phase of the development plan intending a development of 500 ha which was proposed in the Phase-I Study, still more, considering the actual situation of agricultural development during these years, reconsideration of the basic development concept of the further agricultural development plan in the Nejd Region which was proposed in the Phase-I Study should be necessary. Principally, following three articles are proposed s a basic concept for the agricultural development project in the Nejd Region for the next agricultural development phase.

1) Agricultural Development Concept and Sustainable Development
2) Establishment of New Pilot Farm
3) Farming Technology and Technical Transfer

The pilot farm plan was developed based on the Phased Agricultural Development concept. And some parts of the original purpose of the pilot farm concept wasn't achieved and is remaining now also. For example, 1) establishment of systematic control system of groundwater, 2) establishment of training and extension systems and 3) clarification of supporting systems for farm management under commercial base of the overall evaluation on the First Phase have not been able to achieve their purposes. Further, there are many uncertainties concerning groundwater. Consequently, the main objective of establishing the New Pilot Farm(s) is considered as achieving these purposes. Principal roles of the New Pilot Farm are as follows:

1. Evaluation of the groundwater potential in the Nejd region for the next development phase.
2. Achievement of the desert farm management of the Nejd region for the next development phase.

The new farmers' group, who might participate in the proposed plan, should be given enough training at NARS and after the commencement of the New Pilot Farm, they should be given technical transfer from NARS as on-the-job training.

The farm size is proposed as approximately 30 ha, consisting of one centre pivot, one production well and one monitoring well. It is considered that the short term development period is the first four years and the long term development period is from the fifth year. The number of farms proposed would be about three considering the objectives of the Farm, as North of Quitbeet village, North-east of Shasr village and Wadi Mokhawrim.

The cropping pattern to be proposed are based on a reclamation period of four years; perennial cropping of Rhodes grass would be carried out over the whole cropped area of 30 ha, followed by some limited post-reclamation diversification into winter vegetables which would be introduced in a half of the cropped area. The cultivation areas of the grass and the vegetables should be inter changed once in every five years. In addition, the cropping area of each vegetable should also be changed each year by changing the area of one vegetable crop to the other vegetable crop, in order to prevent the problem of replanting failures caused by cultivating the same crop successively.

As it is stated in the Phase-I Study report, it is quite obvious that an agricultural development investing a large amount of capital for desert area with disadvantageous natural conditions to produce agricultural products of low international price, is not really economically viable.

Financial internal rate of return (FIRR) exceeds the discount rate of 6.5% in a case study of governmental subsidy with about 55% for the total initial cost. According to the results of the FIRR estimation, the Omani Government should provide a range of subsidies to implement the New Pilot Farm plan from the financial point of view.

The Plan brings about direct, tangible benefit as well as the secondary or indirect, intangible benefit, which is important in reviewing validity of the implementation of the Plan such as 1) Sustainable Development Concept, 2) Human Resources Development, 3) Creation of New Employment Opportunities, 4) Improvement of Living Standard and 5) Strengthening and Modernisation of Institutional Services.

(2) Recommendations

Agricultural development in the region should be based on the groundwater which is seemed as finite. It is required to set-up some administrative and legal measures to expand the period of the development besides keeping technological evaluations continuously at NARS.

Required set-ups are as follows, as administrative and legal measures;

1) Regulation of new developments by clarifying water resources conditions
2) Enforcement of evaluation potentiality of groundwater
3) Development of new pilot farms to improve the monitoring network
4) Involvement of NARS on research and development of appropriate agricultural techniques, monitoring works and extension activities
5) Setting-up a Development committee with related agencies
6) Setting-up Agricultural supporting system

Besides, it is obvious that NARS as agricultural research station should bear the responsibilities to develop human resources for future developments and clarifications of technical constraints, while enforcing facilities and implements.

1. Introduction

The major objectives of the "The Study on Agricultural Development Project in the Nejd Region (Phase II, Work III)" are 1) to assist the long term monitoring activities at the Pilot Farm and 2) to update the results of agricultural development plan of the previous study. In order to accomplish the objectives, the Study was set forth with the following components.

1) To prepare the detailed design to establish a Pilot Farm (Work I)
2) To examine the development potentiality of the groundwater (Work II)
3) To assist the monitoring survey activities through experimental cultivation (Work III)
4) To provide a guideline for the agricultural development of the region (Work III)
5) To provide on-the job training to the Omani counterpart personnel.

Among the above five issues, the issue 1) was already completed in Work I and the issue 2) was latter excluded from the Scope of the Study by the request from the Government of Oman (July 1992). This Study (Phase II, Work III) was resumed on March 1994 with the request from the Government of Oman after the completion of the construction of the Pilot Farm, to provide guidelines for agricultural development based on the results obtained from monitoring survey works at the Farm, which was latter renamed as "Nejd Agriculture Research Station, (NARS)". The Study area has to cover an area of 8,100 km^2 in the Nejd Region, with NARS located at the Center of the Study Area.

2. Background of the Study

2.1 Agriculture in Oman and Omanization

Oman's economy was entirely based on agriculture and fisheries before 1970, until the start of oil production. However, over half of the total population is still engaged in the agricultural and fisheries industry with fodder crops, dates, lime, watermelon, beans, okra, cabbage etc as main agricultural crops. A noticeable point in the recent economic policies of Oman is "Omanization", which aims to replace the foreign workforce with that of Omanis.

2.2 National Development Plans

The economic development five-year plans began from the First Five-year Plan of 1976-1980. The Third Five-year Plan (1986-1990), aimed at the improvement of social infrastructures in the rural area and promotion of agriculture, fishery and small/middle industries. The main objectives of the past and present development plans in the agricultural sector are summarized as to develop sustainable agriculture to diversify the economy, to increase domestic production and to achieve self-sufficiency in agricultural produce while conserving natural resources and the environment. Ministry of Agriculture and Fisheries (MAF) could achieve nearly 50% self-sufficiency in food production by the end of 1994. During 1990s MAF has set the target of increasing the production of poultry meat, eggs and fresh milk by 100%, and the production of meat from grazing animals by 48% by the year 2000.

2.3 Present Situation in the Nejd Region

The Study Area, Nejd region is located in the southern part of Oman. The Area is approximately 40,000 Km^2 and the centre of the region is the Thumrait town. The topography of the Nejd region is moderately sloping towards north from the coastal mountains at the southern border. The Nejd has a hot desert climate with low humidity during most of the year. Even though the monsoon winds bring rainfall starting from June to September, the catchment area is limited only to the coastal plains and the southern slopes of the mountains. The Study Area is covered by soils derived from limestone and calcareous mudstone or deposits associated with the erosional and depositional processes that have shaped the Nejd region.

The agricultural development in the Nejd region had started in the beginning of 1980s with the development of hand-dug well and flowing well by the local people in Hilat Al-Rakah, Shasr and Dauka. Small scale farms are established recently and the large scale agricultural development farms by commercial company are progressing rapidly in Hilat Al-Rakah and Hanfeet areas. According to the survey of the extension centre in 1995, the total number of farm households in the Nejd region is 155 which consist of 28 fodder cultivation farms and 127 vegetables and fruit cultivation farms. Total cultivated area is 1,337 ha which consists of 608 ha under fodder cultivation and 729 ha under vegetables and fruit cultivation. The most of the fodder grass cultivated is Rhodes grass. According to a MAF study in 1994, the numbers of livestock in the Nejd region are as follows: 16,919 goats, 15,149 camels, 1,558 sheep and 38 cattle. In general, the social infrastructure facilities and services such as domestic water supply, electricity, health, etc. are underdeveloped in the Study Area.

3. Monitoring Survey Results at NARS

3.1 Setting-Up of NARS

The Nejd Agricultural Research Station (NARS) was planned to carry out a continuous monitoring survey on groundwater and agricultural experimental trials in Nejd. Subsequent to the completion of construction works in November 1994, the JICA Study Team took a role of giving advises on the technical aspects for monitoring activities in crop production, soil, ground water, meteorology, water use and cultivation trials.

3.2 Crop Production

Monitoring of crop production is composed of daily observation of plant growth, detailed observation of plant growth during last 10 days before harvesting, hay analysis, quantity and quality of produced hay, estimation of harvest loss, analysis of nutrients and mineral contents in hay and observation of tree growth.

The yield of Rhodes grass from July, 1995 to May, 1996 had conformed to the yearly usual yield pattern of Rhodes grass, which is high in high temperature seasons and is low in low temperature seasons. Hay production of Rhodes grass in Center Pivot field of 30 ha during

July to November, 1995 was 10,000 to 12,000 bales in each harvest , and hay production in January 1996 was 6,100 bales. The hay production was 5.4 to 6.0 ton/ha in each harvest during July to November and 2.1 ton/ha in January, 1996. The yearly hay production during one year from May, 1995 to April, 1996 was 33.7 tones/ha. And these hay is produced with a nitrogen application of 613 kg N/ha/year.

3.3 Soil

(1) Measurement of pH, EC and Soil Organic Matter

Most of the soil pH (1:2.5) values observed fall within the range of 7.5 to 8.5. These pH values may lead to the decreasing availability of nutrients such as Phosphorus. The EC (1:5) values for the NARS soils range between 0.25 to 0.75 mS/cm and the average ECe values were from 2.5 to 5 mS/cm. These ranges are normally considered as slightly saline. When the soil monitoring survey was started, the organic matter content was at a very low level. However at the end of the study period, an organic matter content of approx.1% was observed which can be considered as a significant improvement in the two years of cultivation.

(2) Soil Profile Survey and Visual Observation

Soils in the NARS are classified as Typic Calciorthids (Calcids) and Calcic Yermosols based on the U.S Soil Taxonomy classification and FAO classification respectively. Land suitability classification for irrigated land use is 'S2'. Soils in the NARS are expected to develop during the reclamation phase and by continuous cultivation thereafter. With good irrigation practices, the soils do not constrain for growing a range of crops including Rhodes grass, dates, vegetables (onion, carrot, okra etc.), water melon etc.

(3) Analysis of Soil Chemical and Physical Characteristics

The average value of Cation Exchange Capacity CEC of the NARS soil is 5-10 meq/100g of soil with an average value of 6.5 meq/100 g of soil and these values are considered to be low. The total available nitrogen in the NARS soil is extremely low with an average value of less than 0.01% and the available P value was found as approx.3.5 ppm. The exchangeable K value measured in 1995 ranged between 0.4 - 0.6 meq/100 g of soil and these values measured in 1996 were 0.2-0.3 meq/100g of soil. The exchangeable sodium value of NARS soil was measured as approx. 1 meq/100g. Since the NARS soils are virgin soils with few natural reserves of micronutrients, the availability of the micronutrients is low. The amount of calcium carbonate is very high in the range about of 50%.

The bulk density (wet) of the soil ranges from 1.65 - 1.75 g/cm^3 and the bulk density (dry) ranges from 1.55 - 1.65 g/cm^3. The soil has a coarse texture and has a structure of sandy loam. The average infiltration rate of the center pivot field is fairly high in the range of above 40 mm/hr and in some parts, it is more than 200 mm/hr. The saturated K values range between 0.3×10^{-3} to 5×10^{-3} cm/s (0.26 to 4.32 m/d). Average water holding capacity is 112 mm/m of the soil, which is considered as moderate. The normal range of pF in the soil is 1.50 (3.2 kPa) to 2.35 (22.2 kPa). The average field capacity is 12 - 15% (w/w). Based on these measurements, it was found that there is a good possibility to modify the existing practices of daily irrigation to intermittent irrigation.

3.4 Groundwater

Water resources for irrigation in NARS is groundwater drawn from C aquifer occurring in the top of the lower Umm Er Radhuma Formation (UER) underlying Nejd. During Phase-I study of the Project, two test wells and two observation wells targeting the C aquifer were constructed. Now the two test wells, are used as production wells for irrigation in NARS. And the other two wells have been used as observation wells.

Groundwater monitoring data observed in NARS from October, 94 to October, 96 reveal the fact that the groundwater draw down is almost linear during these two years period. A continuous decline of water level may be the result of pumping from many wells in the region from the aquifer. The unexplainable decrease in water level in NARS indicates probably that this is a complex phenomenon in the area. Not only the continuous monitoring in NARS, but also further monitoring work in the study area including the continuous measurement of water use is strongly recommended for further agricultural development of the Nejd region.

Monitoring works also included periodical water quality checking. According to the result of monthly monitoring of Alkalinity (pH) and Electrical Conductivity (EC), those indicators are stable, namely pH is ± 7.4 and EC is ± 1.600 mS/cm.

3.5 Meteorology

(1) Air Temperature and Relative Humidity

The coldest month is February (22.7°C), while the hottest month is August (32.0°C), with the fluctuations of about 10°C during one year observation period. The difference between daily maximum and minimum temperatures in summer season is higher with 15°C while it was about 10°C in the winter season. The difference in hourly maximum and minimum temperature becomes about 20°C in summer and about 15 °C in winter season. The relative humidity data recorded at NARS reveal that monthly average humidity values fluctuate in a range of 30% and 60%, with ± 10% deviation from a median value of 45%.

(2) Wind

The wind characteristics at NARS can be summarized as follows

1) Average wind speed is slower than Thumrait but faster than Salalah.
2) Effect of monsoon on windspeed seems to be moderate while passing though Thumrait.
3) Seasonal fluctuation is from 2.0 m/s in winter to 6.5 m/s in monsoon period.
4) Prevailing wind direction is South.
5) In clear nights, the usual wind direction is North due to sea and land breeze effect.

(3) Solar Radiation

The mean daily solar radiation follow a cyclic pattern in which the maximum solar energy of 21.43 MJ/m^2 day was observed in April while the minimum of 14.66 MJ/m^2 day was estimated. The actual sunshine duration is shorter (10.7 h) in winter and longer (12.2 h) in summer.

(4) Evaporation

Cumulative evaporation values from September 1995 to August 1996 at NARS is about 3,900mm/year and it might be reasonable to assume an average value of 4,200 mm/year based on the relation between long term average value and 1995 record at Thumrait.

(5) Rain : There was only one event of 53 mm rainfall in June, 96 during the study period.

3.6 Water Use

(1) Record of Water Application

a. Water Application for Grass - The monthly average values of water application varied from 6.2 mm/day to 11.1 mm/day.
b. Water Application for Trees- The monthly average varied from 88 lit./day/tree to 211 lit./day/tree. There are 3,618 trees in the NARS compound.

(2) Estimation of Crop Water Requirement

a. Estimation of potential evapotranspiration (ETo) - The estimated ETo values based on climatological data fluctuate from 4.2 mm/day to 10.4 mm/day and the annual total value is about 2,800 mm/year.
b. Estimation of crop water requirement (ETc) - An estimation of ETcrop with a Kc value assumed as 0.85 varied between 4.2 mm/day to 8.8 mm/day with an annual total of 2383.2 mm. The comparison of this estimated value with that of present annual application of 4429.7 mm indicates that there is a possibility to reduce the water application rate.

3.7 Experimental Cultivation Trials

(1) Rhodes Grass Cultivation Trials

The cultivation trials conducted at NARS are
1) Reasonable methods of irrigation and fertilization for Rhodes grass cultivation
2) Effect of manure application on growth of Rhodes grass
3) Effect of potassium application on growth of Rhodes grass
4) Diagnoses of microelement deficiency and fertilization

Based on the results of the trial 1), it was concluded that applying irrigation water of about 12 mm once in every three days for two months in summer causes yield decrease, but the stocks of Rhodes grass do not die and growth recovers rapidly by restart of daily irrigation. These facts suggest us a water saving method of Rhodes grass cultivation in summer. Further, it was found that the relationship between amount of water and urea applied and yield was linear.

The trials 2), 3) and 4) were conducted only for a short period with limited replications and therefore the results of these trials are not statistically significant at 95 % confidence level. And more precise and repeated trials are required to reconfirm the results.

(2) Farm Management Trial

The purpose of the trial is to clarify the effective farm management strategies for harvest works in 30 ha, to realize the economical combination of farm machinery and labors and to reduce the interruption of irrigation during harvesting. It was observed that the days spent on harvesting works, which was composed of cutting, raking, baling and transporting, was about four days for each quarter of 30 ha and 14 days for the whole field of 30 ha.

(3) Lysimeter Trials

The primary objective is to estimate the crop water balance for Rhodes grass cultivation by clarifying the amount of water use in irrigation, drainage, stored soil moisture and evapotranspiration. For this purpose, the 8 lysimeter plots were divided into control and low irrigation with/no application of manure and the trials were carried out in two replications. The low irrigation treatments showed the low soil moisture contents compared to the control irrigation treatment. Drainage of excess water from lysimeter was observed and its amount decreased during the cultivation period. The value of pH of drainage water showed increasing tendencies in each treatment. On the other hand, the values of EC were not changing during observation period in the controlled irrigation treatment, while that in low irrigation treatment were increasing. This tendency implies that the amount of irrigation water in low irrigation is not enough to provide sufficient leaching of the salts in the soil.

4. Field Survey in the Study Area

4.1 Existing Conditions of the Study Area

(1) Agriculture

There are six farming communities in the Study Area, namely Dauka, Hilat Al-Rakah, Hilat Al-Rakah North, Hanfeet, Shasr and Quitbeet. Noticeable changes in the present farming conditions were observed when compared to that of previous Study in '88/'89. The farms in the Study area can be clearly categorized into two types. One is a small scale farm with a scale of 0.21 ha to 10 ha, adapting traditional irrigation and cultivation system with one or more foreign laborers. The other type is a big scale company farms from 25 ha to 50 ha, with center pivot system with 5 to 10 foreign laborers. About 15 types of crops are cultivated in the Study area. Tomato, water melon, potato, cucumber, cantaloupe and okra are the main vegetable crops. Fruit production like dates, lime and pomegranate plantings can also be identified in the Study area. On the other hand, Rhodes grass production is concentrated at the rapidly spreading big scale farms.

(2) Soil

The reports on previous soil surveys provide good and valid information on the soil conditions of the study area. Some of the general conclusions made from the field survey are as follows :

1) The initial pH (1:2.5) values of the virgin soils are high in the range of 8.5 - 9.5. However, after cultivation is carried out for a considerable period of time, these pH values tend to decrease.
2) The initial EC (1:5) values of the virgin soils are also very low in the range of 0.1-0.2 mS/cm.
3) At some locations in Wadi Quitbeet the soils are alkaline with very low salinity.
4) Among the different areas of the Study Area, the soils at the northern areas such as Dauka and Wadi Bani Khwatar are highly prone to salinity. Therefore while identifying areas for the new farms, careful area selection should be made.
5) The soils in the areas of Hanfeet and Hilat-Al-Rakah have relatively low problem of salinity and alkalinity and if proper irrigation with leaching is followed in these two areas, the soils can be maintained at low salinity level.

(3) Irrigation

In general, basin irrigation method is adapted at small farms. A new sprinkler system was installed through government assistance at Shasr recently. In Hilat Al-Rakah, a company farm installed drip irrigation system for water melon and melon plot substantially besides a center pivot irrigation system. All of the company farms are using center pivot system for grass cultivation. In total there are 24 numbers of center pivots, irrigating an area of 898 ha with an estimated water use of 36.24 MCM/year.

4.2 Groundwater

It is reported that the groundwater reserve in the area is on the order of billions of cubic meters. However, it must be remembered that accelerating drawdown causes significant increases in pumping cost. The economical depth to water surface for pumping is considered to be 100 meters below g.l. There are still uncertainties about the behaviour of C aquifer. The sustainable agriculture development in the area is depending on the efficient groundwater management, which should be established on the basis of understanding the behaviour of the aquifer.

Establishing a groundwater management set-up is essentially indispensable to realize appropriate water use in the area. So, MAF should construct a system to observe continuously the discharge rate of each production well for existing farms in the area to have the following functions.

1) Development control including temporary stoppage of new groundwater development by private sectors.
2) Establishment of monitoring system, including of obligation to measure daily abstraction volume and reporting the log-record
3) Water use monitoring system with remote sensing system map, which might be provided twice a year.
4) Extension services to reduce water consumption at farms
5) Continuous monitoring on both of water use and groundwater level fluctuation.

5. Agricultural Development Plan

5.1 Development Strategies

The strategies of the Agricultural Development Projects in the Nejd Region are

1) Expansion of agricultural production area through optimum exploitation of water resources to contribute for the self-sufficiency.
2) Creation of new employment source for local Omanis and improvement of agricultural labour force.
3) Strengthening and modernisation of institutional services for agricultural experimentation and extension activities.

(1) Present Situation on Agricultural Development in the Nejd Region

NARS was originally planned as a pilot farm, the objectives of which are later modified as much importance was given to scientific research rather than experimentation in the pilot farm. Presently, it seems that the role of NARS is expected as a centre of investigation and research for the desert agriculture. Moreover, according to the existing development studies, large scale development concept might be unrealistic from the view point of sustainable development. On the other hand, a decentralised development strategy with sites spread across the Nejd region would facilitate optimized exploitation of ground water resources. An area of 30 to 50 ha would allow an economically sized centre pivot at each site which could be supported by one or two wells sited 500 to 1,000 meters apart. A reasonable development speed would be two or three sites per year.

(2) Restrictive Factors and Potentiality of Development

For the Agricultural Development Project in the Nejd Region, the water resources is the largest restrictive factor. Therefore, it was suggested that at the beginning there will be a small scale agricultural development and during the first 3 to 5 years there will be a continuous assessment of the aquifer behaviour. The results of the assessment will help to understand the aquifer characteristics and to propose the long term development strategy in the Nejd region.

(3) Basic Concept for Development

The basic concept for the next phase of Agricultural Development Project in the Nejd region should include the following three principles.

1) Agricultural Development based on the concept of Sustainable Agriculture.
2) Establishment of New Pilot Farms
3) Farming Technology and Technical Transfer through NARS

5.2 New Pilot Farm Plan

(1) Objectives of New Pilot Farms

The major objectives of the New Pilot Farm are summarized as follows:

1) Continuous and systematic observation of groundwater and meteorological conditions and evaluation of groundwater potential in the Nejd region
2) Sub-centre of technical transfer of appropriate farming techniques from NARS through extension services
3) Training field for the farmers and agricultural students.
4) Farm management trial as a model farm of the Nejd region.

Irrigated crop area of the New Pilot Farm would be approximately 30 ha, consisting of one centre pivot, one production well and one monitoring well. The short term development period is the first four years and the long term development period is from the fifth year. The proposed number of farms would be about three and located at north of Quitbeet village, north-east of Shasr village and Wadi Mokhawrim. Local people who are living in the settlements around the New Pilot Farms should be selected to take the farming responsibility and be given enough training at NARS.

(2) Farming

It is advisable to cultivate fodder grass, especially Rhodes grass which is agronomically more suitable for the Nejd region. Later, after becoming a self-supporting farm, the commercial crops such as more vegetables and fruits crops could be introduced based on the experimental cultivation at NARS. The cultivation areas of Rhodes grass and the vegetables such as onions, carrots and cabbage should be inter changed in every five years. In addition, the cropping area of each vegetable should also be changed each year by changing the area of one vegetable crop.

5.3 Proposed Facilities of the New Pilot Farm

(1) Farm Layout and Water Use

The general layout of the New Pilot Farm is designed and details of various farm components such as 30 ha irrigated area, 317 m radius center pivot irrigation system, farm compound of width and length of 730 m each, and wind break trees of 25 m width and

1000m length at north and south boundaries are specified. The maximum total daily water demand for separate items is estimated as 4,015 m^3/day for one farm.

(2) Facility and Farm Machinery

The facility plan is designed to the include the following items.

a. Wells, a production well and a monitoring well for each farm.
b. Production Pump, with a pump capacity of 62.0 lit./sec, installed at 50m b.g.l.
c. Irrigation facility, center pivot system for cultivation of grass and bubbler irrigation system for trees.
d. Housings, farm office, workshop and accommodations for farm population, superstructures for farm materials and implements.
e. Electric power plant, two plants with a capacity of 215 KVA, for production pump & irrigators and 25 KVA, for housing and farm office.
f. Water Services, Reverse osmosis plant with a productivity of 4 m^3/per day. to produce drinkable water.
g. Ancillaries include, soak pits and street lights.

Twelve separate items of vehicles and farm machinery such as pick up trucks, tractor, cultivator, harrow, fertilizer spreader, mower, rake, baler, baler carrier are identified and recommended for effective farm activities.

5.4 Cost Estimation

(1) Project Cost

Project cost was estimated to be RO. 372,333 which include construction cost - RO. 203,615, procurement cost - RO. 120,416, physical contingency - RO 32,404 and consulting services - RO 15,900.

(2) Operation and Maintenance Cost

Annual operation and maintenance cost for one farm is estimated as RO 37,418 which includes salary for operators, driver and laborers, maintenance for housing, machinery and equipment, fuel for generators and administrative expenditures.

5.5 Project Evaluation of the New Pilot Farm Plan

(1) Financial Evaluation

The criteria to financially validate the implementation of the Plan are that financial net present value (FNPV) is positive, financial benefit-cost ratio F.B/C is more than 1 and financial internal rate of return (FIRR) exceeds the opportunity cost of capital. Project evaluation has proven that FIRR is drastically below the opportunity cost of capital at the discount rate of 6.5%, FNPV is negative and F.B/C is under 1. It is judged that the implementation of the Plan is not financially sound.

Even though the plan is not validated from financial view point, the governmental subsidy is considered as income of the Plan and hence four scenarios were developed with 0%, 15%, 33% and 55% government subsidies. Among them for the governmental subsidy with about 55% for the total initial cost, FIRR exceeds the discount rate of 6.5%. According to the results of the FIRR estimation, the Omani Government should provide a range of subsidies to implement the New Pilot Farm plan.

(2) Socio-economic Evaluation

Apart from the tangible benefits, the Plan brings intangible benefits on the following aspects 1) Promotion of Sustainable Development Concept, 2) Human Resources Development, 3) Creation of New Employment Opportunities, 4) Improvement of Living Standard and 5) Strengthening and Modernisation of Institutional Services

6. Future Plan of NARS

Future development plan of NARS should be in line with the development direction and hence it should satisfy the prerequisites of (1) legal control against the reckless development by large scale farms is required to avoid free abstractions and (2) coordinated effort among different ministries to exchange related data & information.

6.1 Objectives and Role of NARS

The redefined objectives of NARS are to clarify the scientific principles of sustainable farming practices by monitoring and experiments, to develop suitable farming technologies, and to transfer the technology to farmers in Nejd. To accomplish those objectives, NARS should have the three system roles as briefed below.

1) Research System, responsible and capable to solve the problems of the pilot farms and farmers in close cooperation with the higher order research organizations.
2) Monitoring system, to monitor the groundwater level, soil and water quality, meteorology, diseases and insects, crop production and amount of water use.
3) Governmental services system, involved in development oriented governmental services such as training and extension.

6.2 Organizational Set-up and Functions of NARS

In order to facilitate for the smooth running of daily activities, NARS should establish administrative sections as a) Directorate of NARS, b) Administration Section, c) Research and Development section, d) Monitoring Section, e) Operation and Maintenance System and f) Training and Extension Section, and qualified engineers and sufficient supporting staffs. They might include a) Principal Agronomist, Soil and Water Engineer and Research Scientist on pesticides, b) Crop Scientist, c) Research Associates for pest and disease control, d) Chemical analyst and Laboratory assistants, e) Animal husbandry specialist, assistant and veterinarian, f) Technician I - farm irrigation, g) Technician II - agronomy and h) Assistant agronomists. In addition to their individual responsibilities at NARS, the staff should actively participate in monitoring, training and extension activities outside of

NARS.

While setting-up the NARS organization as mentioned above, External Organizations should be set-up for supporting NARS as follows;

a) NARS Committee - to provide administrative supports to NARS, in such activities as budgeting, procurements, arrangements of required implements and so on.

b) Coordination Committee - to present information and to build up inter-ministry consensus on development.

6.3 Activities Plan

(1) Field Use Plan

1) *Center Pivot field* - 30 ha is used for the field trials of irrigation, cultivation of Rhodes grass and other crops, mechanization, crop rotation, soil management and fertilization, open yard feeding of goats, monitoring, training, etc.

2) *Linear Movement field* - The cultivation trials can be restarted in the linear movement field after the required machinery are available and in future some part of the linear movement area shall be changed to the field of Bubbler Irrigation System for carrying out the research of many types of vegetables and fruit crops.

3) *Lysimeter* - 8 plots of size 3m x 3m is used for the investigation on the water requirement of various crops by seasons and growing stages, the experiments of irrigation, soil management and fertilization.

(2) Plan of Experimental Crop Cultivation and Livestock Farming

To solve the technical constraints in agricultural development of the Nejd region, the research subjects of NARS should include aspects in irrigation, crop cultivation, mechanization, crop rotation and livestock farming.

(3) Monitoring plan

For optimized exploitation of limited resources, continuous monitoring and assessment of following parameters are essential in both NARS and pilot farms.

a. Groundwater level
b. Organic matter and macro- and micro-elements of soils
c. Quality of irrigation water
d. Meteorological monitoring
e. Diseases, insects and weeds
f. Crop production and analysis of nutrients and minerals
g. Amount of irrigation water use

(4) Training and extension service plan

1) Training

Main training activities shall be appropriate crop cultivation and soil management techniques, farm practices, crop protection techniques, irrigation techniques, operation and maintenance techniques of farm machinery, etc. to transfer the successful agricultural technology to farmers, government engineers, agriculture extension officers, farm machinery operators and mechanics and agricultural students.

2) Extension

Main extension activities shall include

a. Technical extension advisory and visiting service.
b. Supply of quality farm input such as seeds, inorganic fertilizers, pesticides, etc.
c. Land preparation service and crop spraying service at a subsidized cost.

(4) Facilities, Farm Machinery and Equipment Augmentation

With regard to the laboratory building, it should be designed to accommodate the following laboratories and each laboratory should be provided with all necessary equipment and instruments.

a. Crop laboratory
b. Physiology laboratory
c. Soil and water laboratory
d. Chemical analysis laboratory
e. Water requirement laboratory
f. Pathology laboratory
g. Entomology laboratory
h. Preparation room
I. Equipment room
j. Laboratory store

Introduction of farm machinery is indispensable for the success of the activities of NARS and therefore in this study, 22 separate items are identified as the required farm machinery to NARS.

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GLOSSARY AND ABBREVIATIONS

Arabic Glossary

Ain	Spring
Aflaj	Plural of Falaj
Athar	Time share on a falaj, approximately half-an-hour.
Bedu	Beduin, normadic Arab of the desert
Falaj	Water distribution system under or above ground
Jabal	Mountain
Jabali	Habitats in Jabal
Jerbeeb	Plain at Jabal foot area.
Khareef	Light monsoon weather conditions experienced between June and September
Qanat	A horizontal well transporting water from an aquifer by means of a tunnelled-allery
Qayd	Dry season from April to June
Sabkha	Salt-flat
Souq	Local market
Wadi	Watercourse dry expected in the rainy season
Wali	Local Governor
Wilayah	Local Governorate
Wilayat	Plural of Wilayah

Abbreviation for Units and Terms

Measurement

Length

mm	Millimeter
cm	Centimeter
m	Meter
km	Kilometer

Area

sq.cm	Square Centimeter
sq.m	Square Meter
sq.km	Square Kilometer
ha	Hectare
fd	Feddan = 0.42 ha
MSM	Million Square Meter

Volume

lit.	Liter
cum	Cubic Meter
MCM	Million Cubic Meter
bal	barrel=31.5 gallon(US)=36 gallon (UK)
gal.	gallon=3.785 liter (US)=4.546 liter (UK)

Weight

mg	Milligram
g	Gram
kg	Kilogram
ton.	Metric Ton

Others

EC	Electrical Conductivity
pH	Potential Hydrogen
ESP	Exchangeable Sodium Percentage
S	Siemens=mho
El	Elevation above the mean sea level
sec	Second

min	Minute
hr	Hour
yr	Year
Min	Minimum
Max	Maximum
℃	Degree Centigrade
%	Percent
FY	Fiscal Year
a.	Annum=Year
mon	month
GDP	Gross Domestic Product
UER	Umm Er Rhaduma (aquifer)

Currency Conversion (Octber 1996)

R.O. (Rial Omani)	1 R.O. = 2.60 US$
US.$ (US Dollar)	1 US$ = 0.385 R.O.

Abbreviation of Organization Names

MAF	Ministry of Agriculture and Fisheries, Oman
DGA	Directorate General of Agriculture
DGF	Directorate General of Fisheries
DGI	Dierctorate General of Irrigation
DGAAF	Directorate General of Agriculture, Animal wealth and Fisheries, Dhofar Governorate
NARS	Nejd Agricultural Research Station
SARS	Salalah Agricultural Research Station
MCI	Ministry of Commerce and Industry, Oman
MC	Ministry of Communications, Oman
MEW	Ministry of Electricity and Water, Oman
MOH	Ministry of Housing, Oman
MPM	Ministry of Petroleum and Minerals, Oman
PDO	Petroleum Development, Oman
PAWR	Public Authority for Water Resources
PAMAP	Public Authority for the Marketing of Agricultural Products
PCDESR	Planning Committee for Development and Enviornment in the Southern Region
MFAJ	Ministry of Foreign Affairs, Japan
JICA	Japan International Cooperation Agency
FAO	Food and Agriculture Organization, United Nations
WMO	World Meteorological Organization, United Nations
WHO	World Health Organization, United Nations
USDA	United States Department of Agriculture
UAE	The United Arab Emirates
GCC	The Gulf Cooperation Council
MMI	Motto MacDonald International
Gibb	Sir Alexander Gibb and Partners
Halcrow	Sir William Halcrow and Partners
Harza	The Harza Engineering Company Limited
GDC	Groundwater Development Consultants
GRM	G.R.M. International Pty.Limited

Project Evaluation

FNPV	Financial Net Present Value
F.B/C	Financial Benefit-Cost Ratio
FIRR	Financial Internal Rate of Return
D/D	Detailed Design
O/M Cost	Operation and Maintenance Cost

CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

The Sultanate of Oman has formulated the Five-Year National Development Plans for promoting its social and economic development. Currently the Fifth Five-Year Development Plan (1996-2000) is enforced aiming at realizing the targeted economic growth through the participation of an increasing number of people in the economic activities in the private sectors as well as sharing the fruits of development through the privatization and Omanization.

The development of the agriculture sector is considered as one of the ways to achieve those objectives because the Sultanate depended on agriculture for hundreds of years by harmonizing with the nature until the time of oil discovery, which was just a quarter century ago. In spite of the oil discovery, the Omani culture remains same as the pre-oil production era and is the foundation for the further development with modernized technology.

Under such circumstances, existence of groundwater was noticed under the Nejd desert region during the oil exploration. Hence the Government of the Sultanate of Oman had made a plan to clarify the development potentiality of the resources for new agricultural development in the region. In this regard, the Government of Sultanate of Oman made a request to the Government of Japan for the technical cooperation of the Study on the Agricultural Development Project in the Nejd Region. In response to the request, the Government of Japan carried out a Study through the Japan International Cooperation Agency (JICA) from 1988/89 to 89/90. The conclusion of the Study focused on the "Phased Development Concept", which suggests the agricultural development in phases over a period of time, because of the lack of sufficient hydro-geological information of the region. While the stress for new development was comprehensible, it suggests to take careful steps of development with detailed monitoring. With such a purpose, an idea of monitoring in a Pilot Farm was suggested as the first step of the approach.

The Government of the Sultanate of Oman requested the Government of Japan in October 1989 to continue the technical cooperation to assist the next step to set-up the Pilot Farm activities and to foresee the potentiality of agricultural development in the vicinity areas with the data to be collected through the monitoring activities of the pilot farm and the information to be provided through related ministries and agencies. In reply to the request, the Government of Japan dispatched a Study Team through JICA in April, 1990, and the Scope of Works (S/W) for the Study was signed between the Ministry of Agriculture and Fisheries (MAF) of the Government of the Sultanate of Oman and JICA.

1.2 Objectives of the Study

The Study aims 1) to assist the long term monitoring activities at the Pilot Farm and 2) to update the results of agricultural development plan of the previous study. The components of the Study are as follows;

(1) Provide a plan of detailed design to establish a Pilot Farm
(2) Examine the development potentiality of the groundwater
(3) Assist the monitoring survey activities through experimental cultivation, and
(4) Provide a guideline for the agricultural development of the region.

Among the above four issues, the issue "(2) Examine the development potentiality of the groundwater " was excluded from the scope by the request from MAF side because of the alteration of administrative demarcation on the issue of water resources evaluation to the newly established Ministry of Water Resources (MWR) from MAF.

1.3 Scope of the Study

The scope of the Study based on the objectives mentioned in the previous section is already explained in the Inception Report (JICA, 1995). The present objective of the Study is to provide guidelines for agricultural development considering the results of monitoring survey works at the Pilot Farm, which was constructed by the Government of Oman. On the occasion of its inauguration on 7^{th} November 1994, the Pilot Farm was named newly as "Nejd Agriculture Research Station, (NARS)".

1.4 Study Area

The Study area is a part of the Nejd, which takes a shape of almost square of 8100 sq.km area, expanding 90km on both direction of North-South and East-West. Nejd Agriculture Research Station is located at the center of this area. Some communities or new developed farms are located in the region. Dauka is at far north along the national highway No.31, and there are some newly developed farms at Hilat Al-Rakah North area which is located at 10 km away from NARS in north west direction. Hilat Al-Rakah is a community consisting of small scale farms, which is located along the link road connecting Shasr with the National Highway. Hanfeet is a newly developing area located at the southern part of the Study Area with several center pivots almost along the national highway. Shasr is a small village with an archeological ruin located at far west of the Study Area. Quitbeet is located at far east of the area, where there is a small community of people living with small farm plots. The boundary of the study area and the locations mentioned above are indicated in the location map.

1.5 Implementation of the Study

The Study is distinguished from the previous study, which was carried out from 1988/89 - 1989/90 by adding the name " Phase-II ". It was progressed through three work-stages as summarized below. The work schedule, including timing for report submission is shown in Fig. 1.1.

(1) Work-1 : Providing a plan of Detailed Design of the Pilot Farm

Concept and outline of the Pilot Farm were defined through a series of discussions with the Directorate General of Agriculture, Animal wealth and Fisheries, the Dhofar Governorate based on the results of the previous phase study. Some additional aspects which are different from the results of the previous study, such as functions of extension services, facilities for veterinary research and research on new crop introduction, were strongly insisted by the Omani side.

In December 1991, a plan of the Pilot Farm Detailed Design was submitted as detailed design reports consisting of drawings, Tender Documents and cost estimates.

The procedures of implementation of construction and procurements were commenced by the Government of Oman. Especially, it should be highlighted that the Department of Irrigation under the DGAAF of the Dhofar Governorate contributed with its full capacity for the construction management of the pilot farm.

(2) Work-2 : Evaluation of Groundwater Development Potential

This component aimed to pursue detailed hydro-geological information and to examine the development potential of the groundwater in the region. While in progress, the work had to be discontinued in 1992, due to administrative reform by which all aspects related to water resources development in the Sultanate were put under the jurisdiction of the Ministry of Water Resources (MWR), instead of the Ministry of Agriculture and Fisheries. Hence a part of the scope regarding this issue was deleted from the original scope of the Study.

Owing to this decision, it was confirmed that MWR would provide all necessary information for evaluating the groundwater potential of the region in coordination with MAF officially.

(3) Work-3 : Assisting the Pilot Farm Setting-Up and Examining the Direction of Agricultural Development.

A request was sent to the Japanese Government in August 1994 to resume the Study after passing of about two years in Pilot Farm construction. Japanese Government dispatched a mission to confirm the progress of the construction and decided to resume the Study from March 1995 for the Work-3 as defined in the original scope. The Pilot Farm was already inaugurated with the attendance of His Excellency, the Minister of Agriculture and Fisheries on November 7, 1994, with a new name as "Nejd Agriculture Research Station (NARS)".

Most of the activities of the Study originated from the objectives of assisting the setting-up of the Pilot Farm in the first one year and examining the direction of agricultural development of the region in the second one year.

CHAPTER 2

BACKGROUND

CHAPTER 2

BACKGROUND

2.1 General

After joining the modern world in 1970, with the discovery of the fossil energy resources, the Sultanate has concentrated to establish the fundamental frames of the nation and infrastructure development through 5-year national development plans up to today. They depended on traditional farming and fisheries as their main source of income before the oil exploration.

This 300,000 square kilometers arid nation is located at the end of east part of Arabian peninsula bounded with United Arab Emirates at far-north part, with Saudi Arabia at west side and with Yemen at far-south part of the Dhofar mountains. Other parts are facing to Arabian Gulf Sea and Indian Ocean. Between northern Oman and southern Oman, huge wide empty desert penetrates and divides the nation into two parts on both the sociological and natural aspects.

Muscat, the capital city of the Sultanate, is the biggest city of the country and is the center of the northern Oman. The city include all the head-quarters of the governmental offices and most of the private firms.

Dhofar region is situated in the southern Oman and is governed by a Governorate, and is located at about 1,000 kilometers south from Muscat. It is said that the culture and history in Dhofar is categorised as Hadramaut culture which includes the mountainous areas of Dhofar and Yemen.

2.2 Socio-economic Situation of Oman

2.2.1 Economic Situation

Since the country started the oil production in 1967, Oman has poured the national income to modernise the country while bearing the direct influence of the world price of the crude oil. After solving the initial setting-up, concentrating to provide social infrastructure, the Government started its efforts to reform the mono-cultural economy to industrial diversification through carrying out a series of 5-year national development plans.

Gross Domestic Product (GDP) growth rate has been kept quite higher as 9%('80-'90) and 5.5% ('91-'93). This has contributed to increase GDP per capita about 9% (1980 to 1993). Besides growing the national economy and economic modernisation, inflation is hardly to be noticed. The people have enjoyed the fruits of the restrained monetary policy by the Central Bank to keep the rate of inflation well under control.

There is an important noticeable point in the recent economic policies of Oman, namely

"Omanization", which aims to exchange the workforce of foreign workers to Omani workforce. They lead it with backgrounds of 1) Increment of educational popularisation, 2) Recent high population growth rate (3.5 / 4.0 %) and 3) Limitation of possible extraction of petroleum at the current production speed.

2.2.2 Agricultural Situation

(1) General Outline

Oman's economy was entirely based on agriculture and fisheries before 1970, until starting oil production, with the meagre trading resources of limited dates, limes and skins. After the initial construction phase of oil industry is completed, over half of the total population is still engaged in the agricultural and fisheries industry, and the 1993 census showed that 50% of the population still live in rural areas.

(2) Production

More than half of 55,000 ha cultivation area (1995) is located in Batinah coast. The majority of farmers are small-scale of less than 1 ha, and productivity is low. Approximately 787 thousand people hold cultivable land and the total number of agricultural workers is around 188 thousands. Main crops are fodder crops, dates, lime, watermelon, beans, okra, cabbage etc.

The value of agricultural and fisheries production rose from RO 17 million in 1970 to RO 156 million by 1994. In 1994, agricultural production totalled around 802,000 t, of which livestock was about 23,000 t and fish production was 114,300 t. Oman is now the leading livestock producer in the Gulf region. According to the 1994 census there are more than 225,000 cattle, 183,000 sheep, 854,000 goats and 98,550 camels, a growth of 6% over the previous year. Agriculture and fisheries are Oman's main non-oil exports, representing 70% of the country's non-oil exports.

Local agricultural products face heavy competition from imported products. The cost of production is comparatively high in Oman as compared to other countries in the region. In addition, there are problems related to labour and marketing while finance is required for introducing modern methods and techniques. In view of these problems, the MAF has adopted package of measures to improve agricultural production in the country.

2.3 Development Plan

2.3.1 National Development Plan

(1) Previous National Development Plans

The economic development five-year plan began from the First Five-year Plan of 1976-1980. With this, the main aims were put on improvement of social infrastructures and establishment of basic industry. At the Second Five-year Plan (1981-1985) the important points were kept by infrastructure improvement and industrial promotion continually. The Third Five-year Plan (1986-1990), aimed at the improvement of social infrastructures in the rural area and promotion of agriculture, fishery and small/medium industries with an influence of large fall of the international oil prices since beginning in the start year.

The Fourth Five-year Plan (1991-1995), besides the past aims of the development strategy also emphasise on establishing a free market economy and the removal of constraints to the free market operation and competition. The previous national development plans are elaborated more in the Appendix A-9.2.1.

(2) Fifth Five-year Plan

The Fifth Five-year Plan (1996-2000) was issued on January, 1996. The basic elements of development aims are summarised as follows:

a. Development of human resources and upgrading the capabilities and skills of the citizens.
b. Create stable economic environment in order to develop private sector.
c. Encourage creation of private sector.
d. Create the suitable environment for economic diversification and make full benefit of the available natural resources.
e. Boosting the living standard of the Omani citizens and reducing differences between the regions and various income categories.
f. Preservation of achievements realised during the last 25 years, maintaining and promoting them.

2.3.2 Agricultural Sector Development Plan

The main objectives of development of the agricultural sector are summarised to develop sustainable agriculture to diversify the economy, to increase domestic production and to achieve self-sufficiency in agricultural produce while conserving natural resources and the environment.

Ministry of Agriculture and Fisheries (MAF) could achieve nearly 50% self-sufficiency in food production by the end of 1994. During 1990s MAF has set the target of increasing the production of poultry meat, eggs and fresh milk by 100%, and the production of meat from grazing animals by 48% by the year 2000.

2.4 Present Situation of the Study Area

2.4.1 General Outline

The Nejd region is located in southern part of Oman between the coastal mountain chains (Al-Qara and Al-Qamar) and the great sand desert "Rub Al-Khali (The Empty Quarter), and belong to the Dhofar Governorate. The Area is approximately 40,000 Km^2 and the centre of the region is the Thumrait town, which is the only urban area in this region.

The Study Area for the agricultural development plan covers 8,100 Km^2 which extends about 90 Km both from east to west and from north to south, and lies at the interior area between 120 Km to 200 Km from Salalah town which is the capital of the Dhofar Governorate. The Area is consists of mainly four sub-zones of Dauka, Shasr, Hanfeet and Quitbeet. Principal settlements are at Shasr which is an oasis from the ancient age and at Quitbeet which is a Bedouins nomadic camp.

2.4.2 Natural Conditions

The topography of the Nejd region is moderately sloping towards north from the coastal mountains at the southern border. The mountains are not only the northern limit of monsoon rain, but also the watershed between the coastal region and the Nejd. The northern margin of the Nejd is bordered by the Rub Al-Khali desert at 190 Km from the coast.

The Nejd has a hot desert climate with low humidity during most of the year and the moist air masses of the south-west monsoon. According to the Thumrait meteorological data, the annual mean temperature is 26°C and the daily variation is very large with a range of 20°C is common throughout the year. The hottest part of the year is the May to September period when the mean maximum temperature is generally over 40°C. December and January are the coolest months and during this period the minimum temperatures of 2 to 6°C are recorded.

The monsoon produces rainfall from June to September, however, the rainfall area is limited only to the coastal plains and the southern slopes of the mountains. Aridity increases in the inland area, forming parallel climatic zone to the coastline. Annual precipitation is highly variable, ranging from 0 to 150 mm. Major rainfall is caused by isolated tropical cyclones which occasionally surmount the divide and cause intense thunderstorms of short duration. Large scale cyclones are supposed to cause floods in the Nejd once in every five years.

The Study Area is covered by soils derived from limestone and calcareous mudstone or deposits associated with the erosional and depositional processes that have shaped the Nejd region.

2.4.3 Population

Population density in the Nejd region is quite low. According to the 1993 census, the total population is 7,439 while the total population of Dhofar Governorate is approximately 189 thousand. Percentage of Omanis of the total population in Nejd is 55%, and the number of families is 912. Most of the people were originally nomads, who didn't have their own permanent residences and the population varied seasonwise; however recently there are many people settled in the locations such as Thumrait, Shasr and Quitbeet. Actually, the Nejd is facing a transition from traditional nomadic pastoralism to urbanisation.

2.4.4 Land Use

The most part of the Study Area is within a remote, almost un-populated, treeless, sparsely vegetated land and is substantially flat with little topography and with wide sandy wadis. There are a few agricultural lands in the area from the view point of extension. Small area of cropping land exists at Shasr village where there are some farms with irrigation from the shallow watertable in the Wadi Ghadun, and at Quitbeet village there are some rather stunted date palms. Presently, large scale commercial farms with centre pivot irrigation system are established in Dauka, Hilat Al-Rakah and Hanfeet. In Hilat Al-Rakah many small farms are distributed. Generally, desert is utilised by grazing of camels and goats, especially near Shasr and Quitbeet. Livestock is the main economic activity in the Area up to now.

2.4.5 Agriculture and Livestock

The agricultural development in the Nejd region started at the beginning of 1980s with the development of hand-dug well and flowing well by the local people in Hilat Al-Rakah, Shasr and Dauka. Small scale farms are established recently and the large scale agricultural development farms by commercial company are progressing rapidly in Hilat Al-Rakah and Hanfeet areas.

According to the survey of the extension centre in 1995, the total number of farm household in the Nejd region is 155 which consist of 28 fodder cultivation farms and 127 vegetables and fruit cultivation farms. Total cultivation area is 1,337 ha which consist of 608 ha of fodder cultivation areas and 729 ha of vegetables and fruit cultivation areas.

The most of the fodder grass cultivated is Rhodes grass (*Chloris gayana*). It is said that Rhodes grass is the most suitable crop to improve the soil structure and is highly tolerant for drought and salinity. At present, some farms are trying to introduce new fodder crops such as Alfalfa, Barley, etc. and also some vegetable crops.

According to the MAF study in 1994, the numbers of livestock in the Nejd region are as follows: 16,919 goats, 15,149 camels, 1,558 sheep and 38 cattle. This shows a characteristic that rate of Cattle (0.1%) is remarkably smaller than goats and camels (50% and 45%) in comparison with the coastal mountain areas.

2.4.6 Social Infrastructures

The Muscat - Salalah National Highway (Road No. 31), paved dual carriageway is crossing from north to south through centre of the Study Area. Three wide graded main roads are extended from this highway on Thumrait to east, west and north-west: Thumrait - Marmul road (Road No. 39), Thumrait - Rakhyut road (Road No. 45) and Thumrait - Shasr road (Road No. 43); however the former two roads are located out of the Area. A graded secondary road of Shasr - Dauka road is passing on the north-west part of the Study. And many motor trucks are crossing in desert. The main flow of traffic is on the Muscat - Salalah road.

In general, the social infrastructure facilities and services such as domestic water supply, electricity, health, etc. are undeveloped in the Study Area. Thumrait urban area where these facilities and services are available and function both as administrative and commercial centre of the Nejd region.

CHAPTER 3

MONITORING SURVEY RESULTS AT NARS

CHAPTER 3

MONITORING SURVEY RESULTS AT NEJD AGRICULTURAL RESEARCH STATION (NARS)

3.1 Setting-Up of Nejd Agricultural Research Station (NARS)

3.1.1 Organizational Setup of NARS

(1) Setup of NARS

NARS was originally planned as a Pilot Farm to carry out a continuous monitoring survey on groundwater and agricultural experimental trials in Nejd. Its name was changed by the Ministry in September 1994 at the time of inauguration of the Farm. The construction of NARS was actually completed at the end of December 1994.

The Japanese Government decided to dispatch a Study Team from March 1995 to re-start the study as mentioned in the Scope of Works based on schedules of staffing and implement procurement as explained by MAF. After commencing the resumption of the Study, these schedules were postponed several times. Those delays caused some discrepancies on study schedules and forced to change the plans after the commencement. Both of procurement of agricultural machines and laboratory equipment are still pending.

Official appointment of staff by the Ministry was supposed to begin in August, 1995 after the Minister's authorization based on the proposal, which was proposed and submitted by DGAAF,SLL. Hence during the period up to the appointment of these staff, the management was carried out as transitional measures under the supervision of DGAAF,SLL. During the transitional period, the role of committee for NARS is undertaken by the Director General's office, with the participation of related departments.

JICA Study Team took a role of giving advises on the technical aspects for the organization as mentioned in the Inception Report. DGAAF,SLL is the counter organization for the JICA Study Team.

(2) Staffing of NARS

Official appointment of the staffs for NARS was made in March 1996, although it was expected by August 1995 in the original plan. Until March 1996, all of the activities of NARS were carried out by the staffs assigned temporarily, who belong to Salalah Agricultural Research Station. Since they were also in-charge of their works in Salalah, there were some lack of management, and they could not contribute fully for NARS during the period.

Fortunately most of the temporary staffs were appointed through the official appointment made in March 1996. List of the staffs can be referred to Appendix-1 There are four main research staffs including Director of NARS, and seven technicians who work as the supporting staffs for carrying out the monitoring and research activities of NARS.

The other supporting staffs for administration, machinery operators, mechanics, electrician and drivers were appointed at the same time of Ministry's appointment but the machinery operators are waiting for the mobilization of machinery at the site. Until the official appointment in March, 1996, only 4 laborers were employed for the farm works at NARS. Presently (October '96) twenty laborers were staying and working at NARS.

NARS hired a contractor to operate the generator system and irrigators at NARS. Presently two operators of the contractor are staying in NARS for these works.

3.1.2 Farming Area, Farm Machinery, and Implements for the Farm Operations

(1) Farm Area

The present layout of NARS is shown in Fig. 3.1.1. The farming area is broadly divided as follows :

1) Center pivot irrigation area - 30 ha
2) Linear Movement irrigation area - 18 ha area
3) Orchard tree areas (drip irrigation system) - 2 ha
4) Windbreak tees - Approx. 2700 numbers

(2) Buildings

All of the building facilities were decided finally and constructed by DGAAF as listed in Table 3.1.1. Necessary furniture for office and accommodation has been transported and placed gradually.

(3) Farm Machinery and Implements

This aspect has been postponed several times from the initial schedule and not yet been arranged at the site. NARS took temporary countermeasures to hire farm machinery from private farms during each harvesting time. The private farms are carrying out the harvest almost at the same time and hence NARS had to wait for the completion of their harvest works. This caused delay of proper harvest time and caused poor re-growth of grass because most of the nutrients in roots were shifted to flower portions as reported in the previous reports (Field Report, Progress Report-I and Progress Report-II.) According to the latest information DGAAF is going to take machinery from other departments in Salalah to NARS as temporary arrangement. And the issue of procurement of new machinery is said to be handled by the Minister's Office now.

The monitoring activities were carried out mostly by the laboratory equipment provided by JICA (Appendix A-1.2). The purchase of the necessary laboratory equipment and other laboratory facilities are planned to be made using the budget in the coming years.

Table 3.1.1 List of Building Facility in NARS

	Descriptions	No.	Dimension	Area (sqm)
1	Main office	1	37.0 x 12.8m	473.60
2	Extension centre	1	27.4 x 17.0m	465.80
3	Workshop	1	20.0 x 12.4m	248.00
4	Booster pump station	1	20.0 x 12.0m	240.00
5	Warehouse	1	32.0 x 5.9m	188.80
6	Power station	1	20.5 x 11.1m	227.55
7	Accomodation	1	31.2 x 12.6m	393.12
8	Staff Accomodation	1	36.4 x 12.6m	458.64
9	Dining hall	1	12.6 x 15.0m	189.00
10	Family accomodation	2	8.5 x 18.0m	306.00
11	Machinery shed I	1	5.5 x 28.0m	154.00
12	Machinery shed II	1	5.5 x 14.0m	77.00
13	Car parking shed (4 nos	4	5.0 x 18.0m	90.00
14	Fertilizer shed	1	28.0 x 11.6m	324.80
15	Cashier's hut	1	4.2 x 7.2m	30.24
16	Labour quarter	1	8.2 x 20.4m	167.28
17	Laboratry	1	20.2 x 24.2m	488.84
18	Stores (3 Nos)	1	5.0 x 15.0m	75.00
19	Veterinary clinic	1	10.6 x 18.8m	199.28
20	Guard huts	2	4.2 x 7.2 m	60.48

Table 3.1.2 Description of Machinery and Implements

Item	Description	Unit	Qty.	Item	Description	Unit	Qty.
A	**Agricultural Machinery**			B.	**Vehicle**		
A-1	Tractor - 4WD, 80ps	Nos.	3	B-1	Station Wagon 4WD	Nos.	5
A-2	Row crop tires for above	Set	1	B-2	Pick-up 4WD	Nos.	2
A-3	Rear Blade - 2m	No.	1	B-3	Micro Bus	No.	1
A-4	Chisel Cultivator 3m	No.	1	B-4	Truck 3ton	No.	1
A-5	Leveling harrow - 4m	No.	1	B-5	Fork lift 2ton	No.	1
A-6	Pneumatic fertilizer spreade	No.	1	B-6	Motor cycle	Nos.	3
A-7	Chain harrow 3.6m	No.	1				
A-8	Crop sprayer 10m	No.	1	C	**Workshop equipment**		
A-9	Mower conditioner 2.5m	No.	1	D	**Office equipment**		
A-10	Hay tedder 6 rows, 7m	No.	1	E	**Office and Building Furniture**		
A-11	Side rake - 4.1m	No.	1				
A-12	Round baler	No.	1				
A-13	Auto-pickup round bale trai	No.	1				
A-14	Front end loader	No.	1				
A-15	Weighing bridge unit	No.	1				

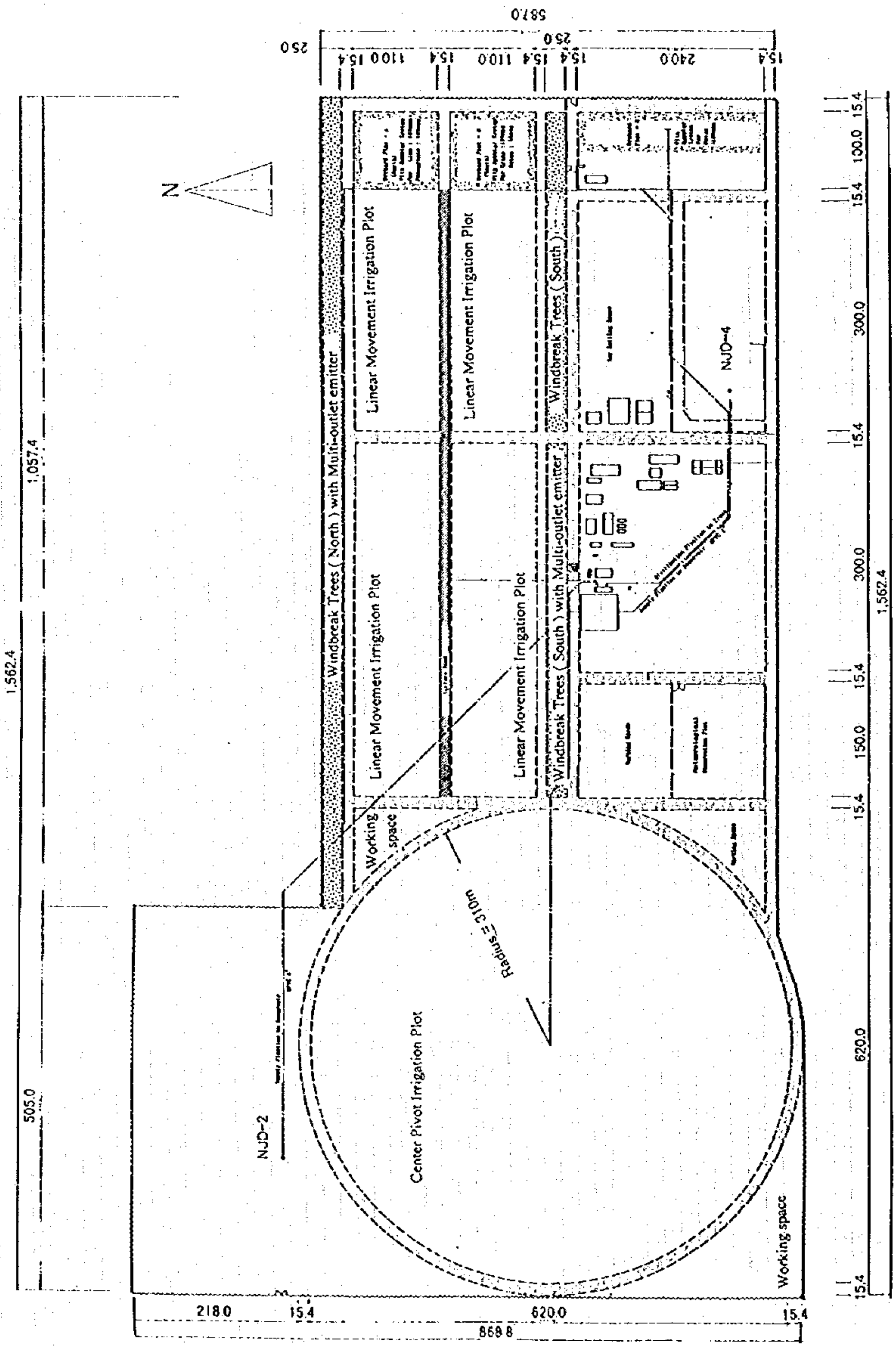


Fig. 3.1.1 Present Layout of NARS

3.2 Crop Production

Monitoring of crop production is composed of daily observation of plant growth, detailed observation of plant growth during last 10 days before harvesting, hay analysis including analysis of moisture contents of hay, quantity and quality of produced hay, estimation of harvesting loss of fodder, analysis of nutrients and mineral contents in hay and observation of tree growth. The monitoring items for the cultivation of Rhodes grass and trees can be referred to Appendix A-2.1.

3.2.1 Cultivation Management

(1) Rhodes grass

1) Cultivation method and growth of Rhodes grass before April, 1995

The cultivation of Rhodes grass was started in September, 1994 and was operated mainly by some contractors until April, 1995 (Appendix A-2.2).

The coverage of Rhodes grass in each field was estimated as approximately 80 % in Center Pivot field, cultivated with *Pioneer* variety and 65 % in Linear Movement field, cultivated with *Callide* variety. Until April 1995, the growth of grass was uneven and poor, and regrowth after harvest was also poor. Besides, the quality of hay was low.

It was considered that uneven and poor growth of grass was mainly caused by poor selection of varieties, less amount and unsuitable way of fertilizer application, deficiency of irrigation water use and time missed for harvesting.

2) Cultivation method and growth of Rhodes grass after June, 1995

Guidelines for Rhodes grass cultivation were provided through discussions with Omani counterparts in May, 1995 (Appendix A-2.3). As a result of improved management with the guidelines, the regrowth of Rhodes grass became uniform and excellent in July, 1995 beyond recognition in comparison with that in May. The good growth of grass is continuing up to now except in some cases, such as delayed fertilizer application and harvest, shortage of irrigation water and so on.

1. Irrigation and fertilization plan

As mentioned later in detail, trial on irrigation and urea application was started on 13 March, 1996 and was carried out until November, 1996. The trial has two levels of daily irrigation water and urea application. The high level is allocated to 15 ha of the western half and low level is allocated to 15 ha of the eastern half of the Center Pivot field. The amounts of daily irrigation water and urea in the high level, namely 12 mm to 15 mm per day of daily irrigation and 67 kg to 80 kg per ha of urea every two weeks by seasons, are same as that of the last year, and amount in the low level are about 60% of the high level.

Table 3.2.1 Method of Irrigation and Fertilization

Season	Amount of irrigation			Amount of urea in every two weeks/ha			Amount of TSP in every three months	
	1995	Mar.,1996 ~		1995	Mar.,1996 ~			
		Level1 (H)	Level2 (L)		Level1 (H)	Level2 (L)	1995	1996
Mar. ~ May	12 mm/day	12	8	80 kg/ha	67	47	270 kg/ha	270
Jun. ~ Aug.	15 mm/day	15	10	80 kg/ha	80	53	270 kg/ha	270
Sep. ~ Nov.	12 mm/day	12	8	80 kg/ha	67	47	270 kg/ha	270
Dec. ~ Feb.	9 mm/day	9	6	80 kg/ha	60	40	270 kg/ha	270

2. Actual application of urea and triple super phosphate

Amount of urea and triple super phosphate for the Center Pivot field of 30 ha during one year from May, 1995 to April, 1996 were 38.72 tones and 24.3 tones which were equivalent to 613 kg N/ha/year and 332 kg P_2O_5/ha/year, respectively. But these amounts in the plan were 1,000 kg N/ha/year of urea and 400 kg P_2O_5/ha/year, respectively. The difference between the planed and the actual urea application was caused by interruption of fertilizer application during harvest for 15 days (Appendix A-2.4.1).

On the other hand, fertilizer application was not carried out regularly according to the plan in summer of 1996. The decreased amount of urea application from late of May to 5 August, 1996 may be reasonable because irrigation water was applied once in every three days during this period due to water shortage (Table A-2.4.2, A-2.4.3, A-2.4.4).

As per the plan, triple super phosphate need to be applied once in every three months; however, triple super phosphate was actually applied only one time from March to September, 1996 (Table A-2.4.2, A-2.4.3).

3. Actual irrigation water use

Irrigation water was applied nearly as scheduled in each season. However, as a result of declining of the groundwater level from late of May to 5 August 1996, irrigation water of the planned daily amount was applied once in every three days due to shortage of water. And the shortage of water by the interrupted irrigation did a great damage to the growth and yield of Rhodes grass (Table A-2.5).

4. Pest control

Many grasshoppers and crickets were observed in Center Pivot field in May to June, 1995 and were controlled by spraying of pesticide (Durban 24; 1 lit./ha ULV using one Micronair AU 8110, with vehicle mounted sprayer) on 19th June, 1995. Many grasshoppers were observed again in August, 1995, in April to June, 1996 and the same pesticide was sprayed.

5. Mechanization of harvest

Rhodes grass has been harvested with tractors, mower, rake, tight baler and trailer by a private contractor because NARS doesn't have his own farm machinery until now.

6. Cutting interval

JICA Team recommended a cutting interval of about 30 to 40 days in summer and 60 to 70 days in winter. The cutting interval in the actual harvesting was 40 to 60 days in summer, 60 days in winter of 1995, 60 days in summer of 1996 except in July harvest when the growth of grass was slow due to water shortage (Table 3.2.2).

3) Growth of Rhodes grass

According to the results of the detailed observation of growth, plant height, number of stems per one square meter and rate of heading before harvest were about 60 to 110 cm of height, 1,500 to 2200 of stems and 27 % to 29 % of heading rate, respectively. And dry matter percentage of top above 10 cm from soil surface, bottom top of 10 cm from surface and roots in 20 cm depth were about 18 % to 27 % of top, 18 % to 41 % of bottom top and 23 % to 68 % of roots, respectively (Table A-2.6.1).

It was defined through discussions that Rhodes grass should be harvested at a time when grass height becomes 60 cm or more and before the heading stems are less than 10 % of the whole stems at the most (Field Report May, '95). However, the results in actual harvesting were above the recommended plant height and heading rate. These were caused by late cutting due to non availability of harvesting machinery in time.

The top above 10 cm from soil surface of Rhodes grass is harvested, and the bottom top and root are kept in the field. The ratio of dry matter weight of top, that is hay, for the total weight, including top, bottom top and root (0 to 20 cm deep), was about 35 % to 61 % in range, 49.5 % in average. That is to say, quantity of dry matter of the bottom top and root (0 to 20 cm deep), which is resources of organic matter of soil, was equivalent to the amount of hay production.

With regard to the interrupted irrigation during two months in summer of 1996, the growth of Rhodes grass under low level treatment has received a great damage and an uneven growth was observed. The field of low level treatment has had many vacant spaces which was caused by dead stocks of Rhodes grass. On the other hand, the crop growth under high level treatment has shown comparatively good growth and the dead stocks have not been observed.

As a result of those facts, it is considered that applying irrigation water of 15 mm per day in every three days, which is the planned daily amount, but actually decreases to about 12 mm per day, during about two months in summer causes decrease in yield, but the stocks of Rhodes grass do not die and growth recovers rapidly with the restart of daily irrigation.

On the other hand, applying irrigation water of 10 mm per day every three days, which is the planned amount but actually decreased to about 8 mm per day every three days in summer damages grasses and stocks of Rhodes grass die in some places. Recovery of growth depends only on spread of stolons and it might take about three months to sufficiently recover. These facts suggest us the saving water method of Rhodes grass cultivation in summer (Table A-2.6.1).

4) Constraints in management of Rhodes grass cultivation

The actual harvesting were carried out after over-growing, even though it was planned to harvest the grass at time of approx. 60 cm height and before the heading stems are less than 10 % of the whole stems at the most. In case of harvesting by contractor, the optimal timing of harvest was easily missed due to the contractor's convenience. And late harvesting caused poor regrowth of grass.

The fertilizer application should be carried out regularly according to the schedule and if the fertilizer application is not followed strictly, the cultivation trials become meaningless. As recommended previously, it is expected to appoint an engineer as the farm manager and a farm foreman.

(2) Windbreak trees

The growth of trees have progressed favorably up to now. The heights of six kinds of trees became 2 m to 4 m and branches are spread to 3 m to 4 m in length and breadth at the end of last year. These sizes are kept by lopping off branches often to prevent split of branches and lodging of trees (Appendix A-2.7).

3.2.2 Hay Production of Rhodes Grass

(1) Yield of hay

1) Change of moisture contents of cut grass in field

Moisture contents of stable hay is 12 to 15% on fresh weight basis. The change of moisture contents of cut grass in the field can be referred to Appendix A-2.8.

The atmospheric temperature in NARS shows periodic change in a day with the maximum at 2 PM, the minimum at daybreak and diurnal range of 15 to 20 Centigrade. On the other hand, the humidity in NARS also shows periodic change in a day all the year round with the minimum of 20 % at 2 PM and the maximum of 80 to 90 % at daybreak.

Drying of cut grass in the field depend upon many factors, such as amount of cut grass, quantity of windrow, temperature, humidity, etc. In order to reduce the moisture content of grass to 15 % of the optimal contents for stable hay, cut grass was required to dry in field one day in hot season and 3 to 4 days in winter with every day raking.

2) Yield of Rhodes grass

The yield of Rhodes grass from July, 1995 to May, 1996 had conformed to the yearly usual yield pattern of Rhodes grass, which is high in high temperature seasons and is low in low temperature seasons.

Hay production of Rhodes grass in Center Pivot field of 30 ha during July to November, 1995 was 10,000 to 12,000 bales in each harvest , and hay production in January was 6,100 bales. The weight of a bale ranges between 12-15 kg.

Table 3.2.2 Hay Production in Center Pivot Field

Harvest No.	Date of harvest	Cutting interval	Treatment (Trial 1)	N kg/ha applied from last cutting	Hay production ton/ha	Harvesting loss ton/ha	Net hay production ton/ha	Dry matter production ton/ha
1 1995	6-Jan.~ 11-Jan.	90	-	100	0.49	-	-	-
2	7-Apr.~ 24-Apr.	92	-	552	1.21	-	-	-
3	6-Jun.~ 12-Jun.	60	-	71	2.72	0.38	3.10	2.79
4	17-Jul.~ 2-Aug.	41	-	107	5.41	0.27	5.68	5.11
5	4-Sep.~ 13-Sep.	49	-	86	5.53	0.22	5.75	5.25
6	3-Nov.~ 16-Nov.	60	-	71	6.01	0.59	6.61	4.88
7 1996	1-Jan.~ 7-Jan.	59	-	107	2.09	0.29	2.39	2.06
8	27-Feb.~ 12-Mar.	58	-	107	3.53	0.08	3.61	3.07
9	4-May~ 14-5	67	High level	64	6.34	0.22	6.56	5.77
			Low level	45	4.23	0.22	4,45	3.91
10	20-Jul.~ 28-Jul.	77	High level	93	1.97	0.12	2.10	1.84
			Low level	61	0.48	0.29	0.77	0.68
11	20-Sep.~ 1-Oct.	62	High level	77	3.44	0.12	3.56	2.71
			Low level	51	1.50	0.05	1.55	1.36

With regard to hay production per ha, productivity was 5.4 to 6.0 ton/ha (4.9 to 5.3 ton/ha on dry matter basis) in each harvest during July to November and 2.1 ton/ha (2.06 ton/ha on dry matter basis) in January,1996.

The yearly hay production during one year from May, 1995 to April, 1996 was 33.7 tones/ha. And these hay is produced with nitrogen application of 613 kg N/ha/year. On the other hand, it was predicted in the guideline in May, 1995 that hay of 40 ton/ha/year would be produced with a nitrogen supply of 1,000 kg/ha/year.

The Rhodes grass yield under high level treatment in May 1996 exceeded the maximum yield observed in last year. Amount of irrigation water and urea of the high level treatment was the same as the last year.

However, the yield at high level location in July in the midst of interrupted irrigation due to water shortage, decreased to 36% of the yield in the same month of last year.

The yield with high level treatment location on 20 September, which is 46th day after restarting daily irrigation, recovered to 52% of the yield in the same month of the last year.

3) Growth rate in hay production

Relationship between average daily increase of dry matter per ha (growth rate) and total amount of nitrogen applied during cutting interval in each harvest is shown in Figure 3.2.1, with use of data in Table 3.2.2.

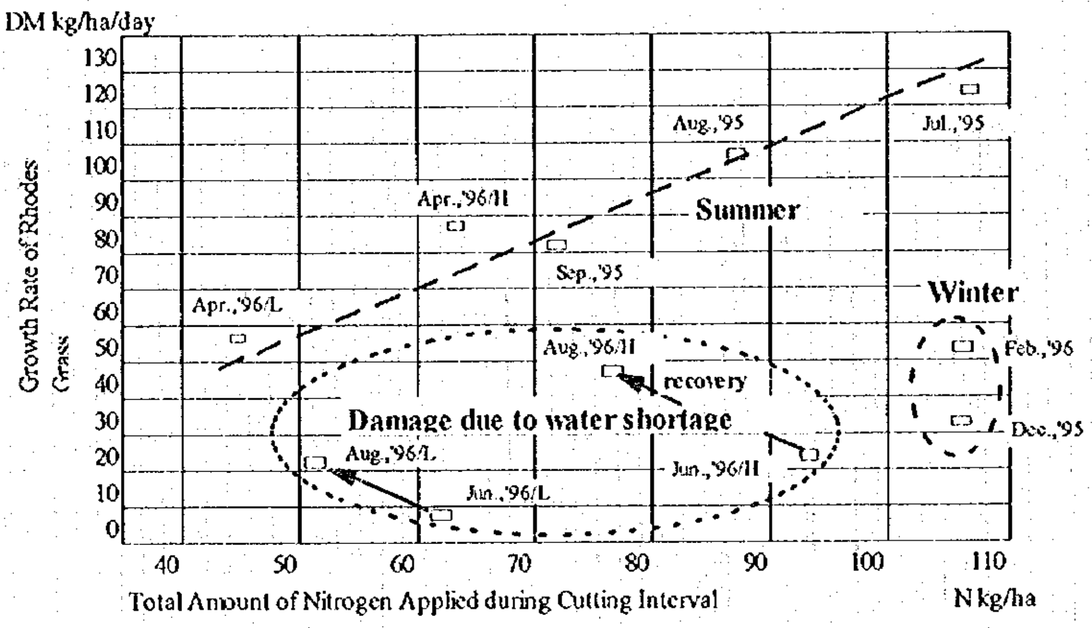


Figure 3.2.1 Effect of nitrogen application on growth rate of Rhodes grass

The effect of nitrogen application for growth rate of Rhodes grass as follows;

1. Growth rates of Rhodes grass (DM kg/ha/day) are different in summer and winter. Growth rate is greater in summer, from March to October, than in winter, from November to February.

2. In summer, relationship between average daily increase of dry matter per ha (growth rate) and total amount of nitrogen applied during cutting interval in each harvest is linear within the upper limits of yearly amount of nitrogen application of one ton per ha.

3. The low growth rates observed in June, 1996, were caused by water shortage, and in this figure, these points were far below from the linear relationship between growth rate and amount of nitrogen application. This shows that the growth rates in the period receive more strongly the effect of shortage of irrigation water than the effect of nitrogen application.

   The growth rates from August to September, during 46 days after the restart of daily irrigation, move toward the usual line in the figure, but not yet entirely recovered. Careful observations are expected when the growth rate of Rhodes grass recovers fully.

(2) Contents of nutrients and minerals of hay

Both of Farm 1 and Farm 2 in Nejd have cultivated Rhodes grass for past five years or more. Characteristic feature of hay of NARS in June, 1995 is less P and less crude protein, compared with hay of other farms. The growth of Rhodes grass at that time is considered to be a reason for the low nutrient content and improvement of cultivation had no effect on the growth till then (Appendix A-2.9).

However, hay harvested in March, 1996 showed an increase in crude protein and P values. Contents of micronutrients of hay are in the lower ranges for all samples. As discussed in the next section 3.3, the availability of microelements in the virgin soil of NARS is less. Besides, the supply of microelements through irrigation water is also less, since the irrigation water contains low level of microelements.

In order to verify the significance of microelements, microelements trials were started in NARS and further details are described in section 3.7.

3.3 Soil

Since April 1995, the following soil monitoring surveys were carried out in NARS at regular intervals, in order to analyze the change of soil conditions during the cultivation period.

1) Measurement of pH, EC and soil organic matter
2) Soil profile survey and visual observation
3) Analysis of soil chemical characteristics
4) Analysis of soil physical characteristics

The results of the above monitoring surveys are discussed below :

3.3.1 Measurement of pH, EC and Soil Organic Matter

Soil samples were taken regularly at monthly intervals from the plots of center pivot irrigation, windbreak trees, fruit trees, and pH, EC measurement were carried out. Organic matter measurement was carried out at every three months interval. The results are shown in Appendix Table A-3.1.

(1) pH

There have been no significant changes in the pH values of the soils during the past one and half years of monitoring period and most of the pH (1:2.5) values observed in this period fall within the range of 7.5 to 8.5. These pH values are considered to be slightly higher than the normal pH value, which may lead to the decreasing availability of nutrients such as Phosphorus. The major effect of a basic pH is to reduce the solubility of the micronutrients, such as Cu, Fe, Mn and Zn. Most micronutrient problems caused by high soil pH are solved by adding special fertilizers such as water soluble chelates which are stable but soluble complexers of the metal ions (although susceptible to microbial decomposition). A high pH value decreases the bacterial activity and hence the nitrification of the organic matter.

(2) EC

The EC (1:5) values for the NARS soils range between 0.25 to 0.75 mS/cm (except a slightly higher EC values for a few samples) and the average value lies around 0.5 mS/cm. ECe for these arid soils are normally 5 to 10 times of EC (1:5) values and the average ECe values were 2.5 to 5 mS/cm. These ranges are normally considered as slightly saline. Rhodes grass is a salt tolerant crop and the yield reduction is very less in this range. However if the ECe values go above 10 mS/cm, then there shall be an yield reduction of more than 10%.

Salinity is a major concern in these arid soils and irrigation is required for crop growth although it may itself induce the salinisation unless salts are leached away regularly. Average EC of irrigation water is 1.6 mS/cm, and according to USDA and FAO classification of irrigation water, the intensity of salinity problem to be caused by EC of irrigation water within a range of 0.75 to 3.0 mS/cm is considered as 'moderate'. Unless leaching is carried out regularly, the salt content of the soil would increase. Since the amount of irrigation applied in the NARS during the past 18 months satisfied the leaching requirement, the salt content in the NARS was kept under control within the same range of 0.25 to 0.75 mS/cm.

(3) Organic matter content

Organic matter content of the soil was measured at every three months interval and the results are shown in Appendix Table A-3.1. When the soil monitoring survey was started, the organic matter content was at a very low level and only traces of organic matter have been measured. However during the latest measurement made in July and October, 1996 an organic matter content of approx.1% was observed in the Center Pivot field which can be considered as a significant improvement in these two years of cultivation.

Generally, most of the cultivated soils contain 1 - 5% organic matter in the root zone, which has a significant influence on the physical properties of the soil and strongly influence its chemical and biological characteristics. Soil organic matter acts as the nitrogen reservoir and furnishes a large portions of the soil phosphorus and sulphur. It loosens up the soil to provide better aeration and water movement.

3.3.2 Soil Profile Survey and Visual Observation

The soil pits were dug in the Center Pivot field to observe the soil profile characteristics and for taking the samples for detailed physical and chemical analysis. The results of the soil profile description are shown in the Appendix A-3.2.

Soils in the NARS are classified as Typic Calciorthids (Calcids) and Calcic Yermosols based on the U.S Soil Taxonomy classification and FAO classification respectively. Land suitability classification for irrigated land use is 'S2' with some limitations for crop cultivation such as coarse texture, low fertility etc. Under Nejd climatic conditions, the crop water requirements are high.

Mostly the soils are immature in terms of soil development and has a weak development of the soil horizon and soil structure. Soils in the NARS are expected to develop during the reclamation phase and by continuous cultivation thereafter. With good irrigation practices, the soils do not constrain for growing a range of crops including Rhodes grass, dates, vegetables (onion, carrot, okra etc.), water melon etc.

3.3.3 Analysis of Soil Chemical Characteristics

The soil samples were taken from each horizon and the soil chemical analyses were carried out at regular intervals. The results of the soil chemical analyses are shown in Table A-3.3. The soil chemical characteristics based on the results of the chemical analyses are discussed below :

(1) Cation Exchange Capacity

Cation Exchange Capacity (CEC) estimates are commonly used as a part of the overall assessment of fertility of the soil and possible response to fertilizer application. CEC of the NARS soil for the samples taken in 1995 was low in the range of 3-9 meq/100g of soil and the average value is 5 meq/100g of soil. The latest samples taken at the end of September 1996 showed a slightly higher CEC value of 5-10 meq/100g of soil with an average value of 6.5 meq/100 g of soil. FAO quotes that CEC values of 8 to 10 meq/100g is considered as the minimum values in the top 30 cm of the soil for satisfactory production under the irrigation, provided that other factors are favorable and CEC values of less than 4 meq/100g of soil indicate a degree of infertility. Since the soils in NARS are sandy loam to sandy clay loam with a higher percentage of fine sand, the CEC of the soils is low with a very low fertility.

(2) Total Nitrogen

Nitrogen occurs in soils in several forms : organic compounds, nitrate and nitrite anions, and ammonium ions, which can occur as exchangeable cations; and nitrates are the main forms of N used by plants. Apart from application of N fertilizers, the main source of N in soils is the break down of organic soils. The total available nitrogen in the soil is extremely low with an average value of less than 0.01%. Normally, according to a broad rating, the total N content by Kjeldahl method below 0.1% is considered as low and a value of 0.2 to 0.5% is considered as medium. The NARS soils are virgin soils and although Nitrogen fertilizer application has been carried out, it was mostly consumed by the crops. Besides, the available organic matter is also low. Therefore the total available nitrogen is very low.

(3) Available Phosphorus

Phosphorus occurs in soils in both organic and inorganic forms, the latter usually being the most important for crop nutrition. An available P value of above 8 ppm is considered as adequate for grass and a value of less than 4 ppm is considered as deficient. In the NARS soils, the available P is very low. In the last measurement, it was found that the available P value was approx.3.5ppm. Since the available P value is low, the response for the fertilizer application was very significant and a significant increase in the yield was noticed in the NARS after the application of triple super phosphate fertilizer.

(4) Potassium

It is considered that potassium is apparently not necessary for these type of soils and the irrigation water also contains an appreciable amount of potassium. Normally if the exchangeable K is above 0.4 meq/100 g of soil, no K fertilizer is required. The exchangeable K value measured in 1995 ranged between 0.4 - 0.6 meq/100 g of soil and these values measured in 1996 were 0.2-0.3 meq/100g of soil. In the PDO farm, where experimental trials and fertilizer research are done for the past 10 years, K fertilizer is applied regularly. In order to verify whether there is any significant difference towards the application of K fertilizer, experimental trials are carried out in NARS. The results are discussed in section 3.8.

(5) Exchangeable Sodium

Its presence or absence is usually not detrimental to plant nutrition. However, when Na is present in significant quantities, particularly in proportion to other cations present, it can have an adverse effect, not only on many crops, but also on the physical conditions of the soil. During the latest soil analysis in September, 1996, the exchangeable sodium value of NARS soil was measured as approx. 1 meq/100g. The SAR (Sodium Adsorption Ratio) value of the NARS soil in the Center Pivot field was approx. 3 during the first soil analysis in May 1996 and the average SAR value measured in September 1996 was approx. 5. Since the SAR of the soil is below SAR limit value of 13, at present the NARS soil can be considered to be in non-sodic condition.

(6) Micro-nutrients

The micro-nutrients considered to be essential for plant growth are Cu, Fe, Mn, Zn, Mo, and B. The availability of micronutrients to plants is influenced by many soil and environmental factors. In particular Cu, Fe, Mn and Zn are affected by the redox potential of soil, and their availability can differ considerably from day by day. The availability of micronutrients in the NARS soil are shown in Appendix Tables A-3.3. Since the NARS soils are virgin soils with few natural reserves of micronutrients, the availability of the micronutrients is less. The availability of micronutrients such as Fe, Mn, Cu and Zn decreases significantly with an increase in pH and the nutritional deficiencies are quite common in the calcareous soil and the soils of high pH. In order to verify the significance of micronutrients, micronutrients trials were started in NARS from October, 1996. Further details are described in section 3.8.

(7) Calcium Carbonate and Gypsum

The amount of calcium carbonate is very high in the range about of 50% and these types of highly calcareous soils are very common in the arid regions. Gypsum has been noted only at the southwestern corner of the center pivot irrigation system and only traces of gypsum was found in most of the other locations of NARS. Soils with a high gypsum content normally form a cemented layer which impede root growth. A gypsum content of less than 2% is favorable for root growth and values between 2 - 25% have little impact on root growth and above 25%, it will have adverse effect and reduce the yield substantially. The soils in NARS have only few traces of gypsum and therefore the problem is negligible.

3.3.4 Analysis of Soil Physical Characteristics

Soil physical properties were measured by taking undisturbed soil samples from the field. The bulk density (wet) ranges from 1.65 - 1.75 g/cm^3 and the bulk density (dry) ranges from 1.55 - 1.65 g/cm^3. The soil has a coarse texture and has a texture of sandy loam. The infiltration rate of the Center Pivot field was measured by using double ring infiltration meter and the results are shown in Appendix A - 3.4. As shown in the Table A-3.4, the average infiltration rate of the center pivot field is fairly high in the range of above 40 mm/hr and at the southwestern parts of the field, it is more than 200 mm/hr. This range is classified as moderately rapid to very rapid. Because of the high infiltration rates, these soils are not suitable for surface irrigation system, and overhead sprinkler and drip irrigation systems are more suitable.

The saturated hydraulic conductivity of the soil cores were measured and the results are shown in Appendix Table A-3.5. The saturated K values are almost similar to all the horizons and ranges between 0.3×10^{-3} to 5×10^{-3} cm/s (0.26 to 4.32 m/d). The hydraulic conductivity in this range is normally classified as moderately rapid and usually the soils with a texture of fine sandy loam, sandy loam, loamy sand and fine sand have saturated K in this range.

The soil moisture characteristics of NARS soil and its available water holding capacity (AWC) is shown in Appendix A-3.6. Average water holding capacity is 112 mm/m of the soil. An available water holding capacity of less than 60 mm/m is considered as low and 60 - 120 mm/m is considered as moderate. AWC is an important parameter in order to decide the frequency of wetting and the duration of dry periods between irrigation applications.

Tensiometers were installed at various locations of the center pivot irrigation system and the soil moisture tension values were observed. Since the irrigation system was irrigating every day during the measurements, except before harvest, the amount of soil moisture varies with respect to time of measurement. As shown in the Table A-3.7, the normal range of pF in the soil is 1.50 (3.2 kPa) to 2.35 (22.2 kPa). During these measurements, the irrigation was carried out during the night time. Therefore, the soil reaches its higher pF level of 2.35 at 1800 hrs, due to evaporation and percolation losses from the soil. And after the irrigation during the night time, the pF is reduced to its lower level.

Soil moisture measurement was also made regularly and the soil samples were taken at four depths of 0 - 30 cm, 30 - 60 cm, 60 - 90 cm and below 90 cm. The results are shown in Table A-3.8. The soil moisture remains almost in the same level at all the four depths. Because of its high infiltration rate, the water moves faster downwards and since the irrigation is carried out everyday, all the profiles are wetted to its field capacity level. Any water supplied above this level is drained freely. In order to determine the field capacity, a field experiment was conducted in the field and the results are shown in Table A-3.9. Average field capacity is 12 - 15% (w/w), which is also similar to the laboratory measurements. In order to minimize the seepage and evaporation losses, the practices of intermittent irrigation can be started as an experimental trial in NARS.

Based on the available water holding capacity and the soil moisture measurements, it was found out that there is a good possibility to modify the existing practices of daily irrigation to intermittent irrigation. As mentioned above, the average AWC of NARS soil is 112 mm. If the readily available soil moisture is assumed as 2/3rd of the AWC, approx. 75mm can be considered as readily available soil water. If the daily water requirement of the crop is considered as 15mm, the crop can obtain its full water requirement for 5 days, even without any irrigation. If this practice is found to be suitable through the experimental trials, the intermittent irrigation method can be adopted in the other farms of the region.

3.4 Groundwater

3.4.1 Groundwater Monitoring

Water resources for irrigation in NARS is groundwater from C aquifer underlying Nejd. It is known that four aquifers occur in the Tertiary carbonates in the area. These four aquifers are A aquifer occurring in Dammam or Rus Formations, B aquifer occurring in the upper Umm Er Radhuma Formation (UER), C aquifer occurring in the top of the lower UER and D aquifer occurring in the lower part of the lower UER. Particularly the C aquifer has been expected as the productive and suitable water resources for agriculture. The outline of hydrogeology and the schematic hydrogeological profile in the area can be referred in Appendix A-4.2 & A-4.3.

During Phase-I study of the Project in 1988, two test wells and two observation wells targeting the C aquifer were constructed in the proposed site. Now the two test wells, which are NJD-2 and NJD-4, are used as production wells for irrigation in NARS. The others, namely NJD-1 and NJD-3, have been used as observation wells. The locations of these wells are shown in Appendix 4-6.5.

Changes in groundwater level are caused by various factors, some are artificial and others are changes of natural conditions. Most of the natural conditions in general are seasonal or daily variations such as precipitation, evaporation and atmospheric pressure. It is considered that the most effective artificial factor in the area is pumpage from wells around the area.

A continuous decline of water level may be the result of pumping from many wells in the region from the aquifer and it may cause a reduction of yield due to the drawdown. Therefore the water level monitoring is considered as one of the most important purposes of NARS operation.

Monitoring works also include periodical water checking at the site and detailed analysis periodically. According to the result of monthly monitoring of Alkalinity (pH) and Electrical Conductivity (EC), those indicators are stable, namely pH is +/- 7.4 and EC is +/- 1.600 mS/cm. Also the result of detailed water quality analysis indicates that there was no particular difference with the result in July 1995, June 1996 and September 1996.

3.4.2 Water Level Fluctuations

Pumping from the production wells started from September 15, 1994 for irrigation at NARS. The water levels in the observation wells have been recorded continuously since October 1993.

The highest level in a day on the charts were read and arranged in Fig. 3.4.1 and tables shown in Appendix 4. Fig. 3.4.1 shows water level (piezometric head) fluctuations of C aquifer in NARS from October 1993 to October 1996 and it is summarized as follows.

(1) Before starting pumping at NARS (from October 1993 to September 1994)

The long term tendency, which is the decrease of water level followed by the increase for several years, seems to be effected by the hydrological and hydro-geological conditions in the area. Water levels fluctuated around 1.5 meters below ground level for NJD-1 and 2.5 meters b.g.l for NJD-3.

(2) From September 1994 to April 1995

From September 1994, when NARS was started, to April 1995, when the study team reset the recorder, the groundwater levels on the charts had fluctuated strangely. The data of water levels may not reflect the actual fluctuations because of improper setting of the recorder scale.

The depth to water surface was 2 or 3 meters in September 1994 and it became about 10 meters by the end of April 1995 as a result of pumping in NARS during this term. The decreasing rate of water level was 3.3 cm/day, or 12 m/year.

(3) From May 1995 to February 1996

The term may be divided in two periods. The first period is from May to October 1995 and the second period is November 1995 to February 1996. During the first period the depth to water surface lowered from about 10.2 meters to about 14.7 meters and the decreasing rate was 2.5 cm/day. At the beginning of November, the water level recovered a little which may have followed the reducing of water discharge. After that, the decreasing rate dropped to 1.5 cm/day, as the depth to water surface lowered from about 13.5 to 15.2 meters from the middle of November to February 1996.

(4) From March 1996 to October 1996

The decrease of the drawdown rate described above was a passing phenomenon. From March to October 1996 the depth to water surface continued to fall from about 15.2 to 22.2 meters. The drawdown rate during the period was 2.86 cm/day, or 10.4 m/year. However the record shows noticeable changes and differences of the rate in the term.

1) March

During March the water level decreased generally except in the middle of March when the pumping was stopped. The level dropped by almost 2 meters from about 15 to 17 meters for one month. The decreasing rate was 6.6 cm/day.

2) April and May

The water level was stable for the first half of April, and after that the level was going down by about 0.6 meters, 5 cm/day. Throughout April the pumping was continued as usual. In May the level came to be stable again for the first week, and then the level had decreased until the end of the month with the rate of about 3.0 cm/day. The stable level may be caused by the reducing of water discharge.

3) June and July

The operating condition of the production wells was changed at the end of May. Consequently the water level fluctuated widely reflecting the pump operation. The general tendency of decreasing water level continued until the middle of July with the rate of about 3.0 cm/day, though the total withdrawal during this period was less than half of regular discharge volume. During the latter half of the month, the water level was stable in general while reflecting the pumping operation.

4) August

In the beginning of August, once the pumping operation returned to ordinary condition the water level lowered sharply. During the month the decreasing rate was more than 8 cm/day, from about 19.5 to about 22.1 meters.

5) September, October

The water level has been relatively stable since the beginning of September. The level have fluctuated around 22 meters. The average discharge volume from 5 Aug. to 19 Sep. was 3599 m3/day and the value from 20 Sep. to 15 Oct. was 2614 m3/day.

From September 1994 to October 1996, the water level in NARS decreased from around 2 meters below g.l. to around 22 meters b.g.l. with the mean discharge rate of about 2600 m^3/day.

3.4.3 Water Level Change and Pumping Rate

Most of the temporary water level rises on the record can be explained with pump stoppage or reducing discharge volume of water. Fig.3.4.1 shows the water level recovered momentarily when the discharge volume was less than 2000 m^3/day. However the general tendency of decreasing water level continued throughout June and July while the average discharge rate was about 3000 m3/day during the period. There are other rises or stable condition in water level which can not be explained with only pumping condition in NARS.

Table 3.4.1 and Fig. 3.4.2 show the mean pumping rate and the drawdown which is expressed in differences in monthly mean water level from the previous month from June 1995 to October 1996. Daily average pumping rate, that is, the amounts of discharge are indicated in bar charts from the top to the bottom in Fig. 3.4.2. The lines in the Fig. 3.4.2 which indicate drawdown from the previous month are changing according to the amount of discharge generally. However there seem to be no correlation between the quantity of discharge and the value of drawdown. And the reverse moves of drawdown with discharge are noticed in some periods, which are from August to October 1995 and from December 1995 to January 1996. Recovery is also observed from October to November 1995 and from September to October 1996 though pumping continued during the terms. These phenomena may indicate that there is seasonal recharge to C aquifer and/or that the piezometric head in C aquifer is affected by artificial factors around the site. The long term monitoring will make clear these points.

3.4.4 Future Trend of Water Level

A hydrogeological theory commonly indicates that the 50-70 % of drawdown due to a long term pumping occurs in the first one year after starting abstraction. Although two years have already passed since NARS started to operate, the water level continues declining linearly as shown in Fig. 3.4.1.

Any existing groundwater models do not explain the declining tendency, or the water level decreasing in NARS is probably very complicated phenomenon. Conventional aquifer test analyses cannot be effective to obtain the reliable aquifer parameters of C aquifer so far. Therefore it is difficult to predict exactly the future trend of water level at the present. However temporarily and tentatively the future trend is predicted that the water level may reach 50 meters below g.l. in the middle of 1999 or 2000 if the drawdown continues linearly in the area.

3.4.5 Conclusion

Two years have passed since NARS started its operation. During the period the piezometric head declined about 20 meters from around 2 meters below g.l. to around 22 meters b.g.l. in the site. Although seasonal changes of decreasing rate is observed, the level generally continues declining so far.

It is considered that the seasonal changes of decreasing rate are caused by artificial and natural factors. Most likely the artificial factor is the pumping condition at NARS itself and around the site. At the present it is not obvious whether the recharge to C aquifer occurs and effects the water level fluctuation or not.

It is difficult to predict the future trend of water level fluctuation being a complicated phenomenon in the area. However a tentative and graphical analysis shows that the water level may reach 50 meters b.g.l. in the middle of 1999. Consequently the continuous monitoring of water level is important to clarify the behavior of groundwater and to manage the water use in the area.

Fig. 3.4.1 WATER LEVELS in NARS (Oct. '93 - Oct. '96)

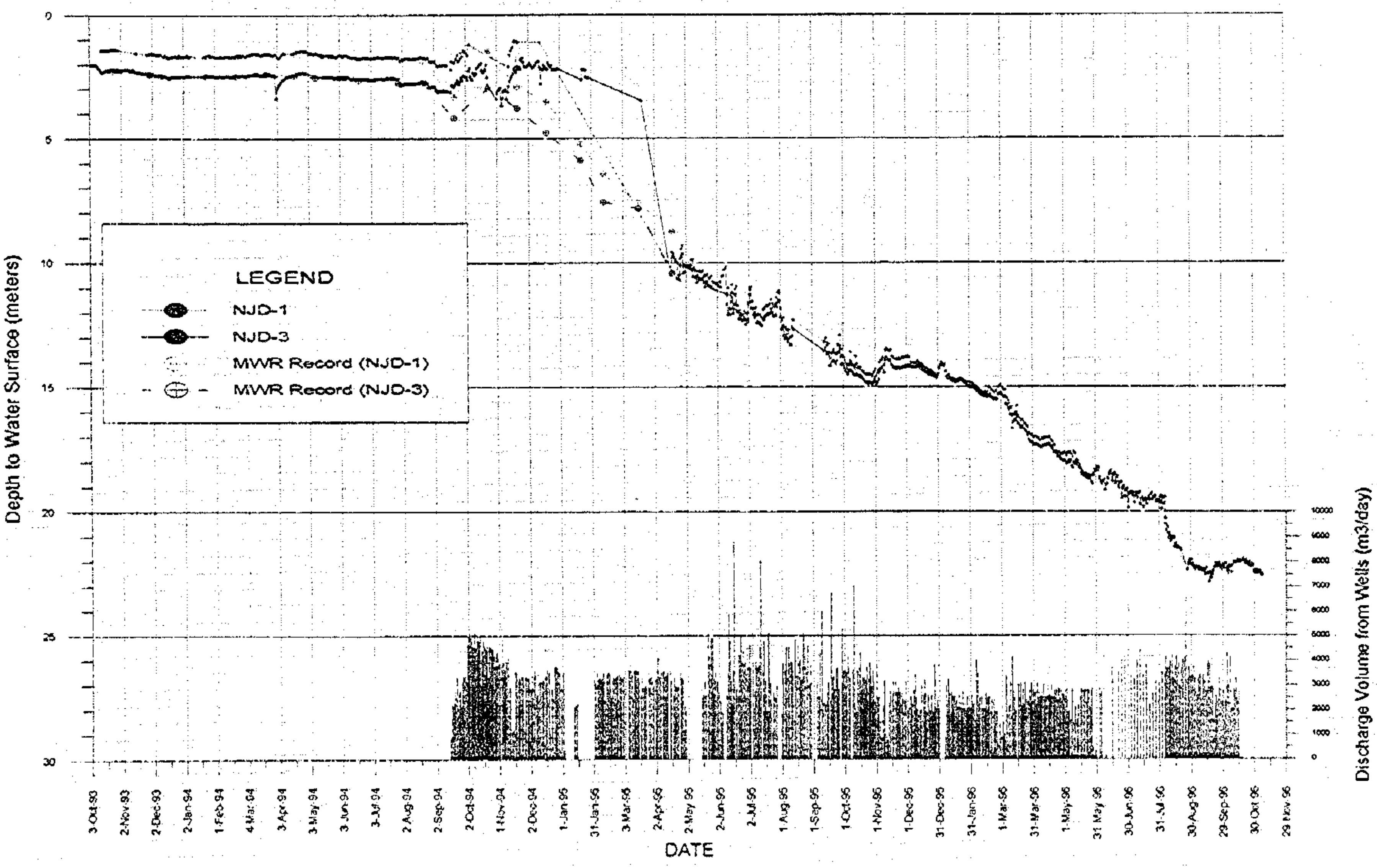
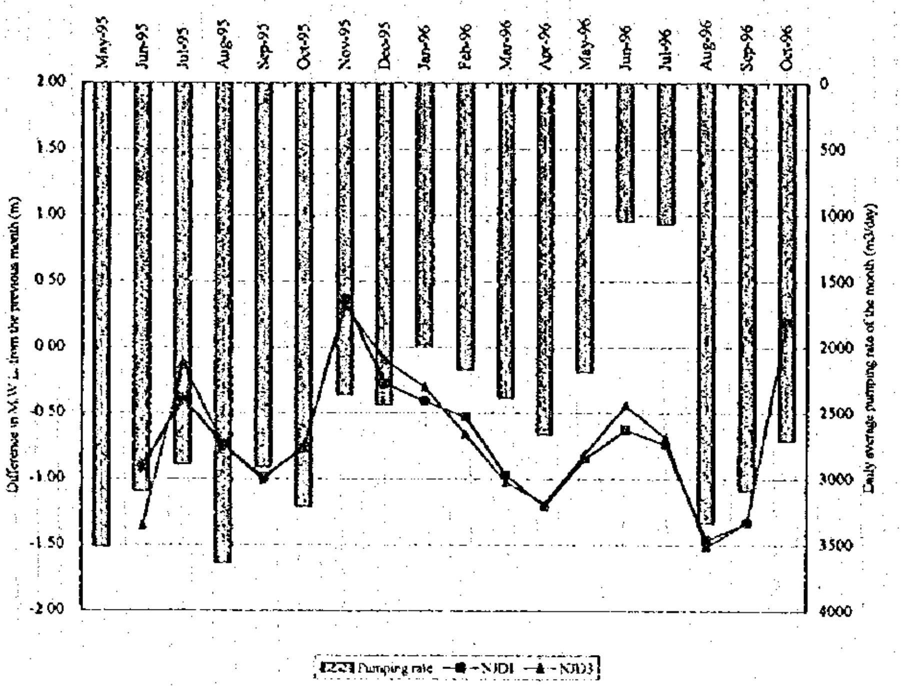


Table 3.4.1 Drawdown - Pumping Rate

		1995	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Pumping rate (Daily average)	(m3/day)					3520	3098	2893	3641	2916	3214	2364	2440
NJD1	Difference in M.W.L. from the previous month	(m)						-0.91	-0.39	-0.74	-0.98	-0.77	0.35	-0.28
	Mean W.L. of the month	(m)					10.43	11.34	11.73	12.47	13.45	14.22	13.87	14.15
NJD3	Difference in M.W.L. from the previous month	(m)						-1.35	-0.12	-0.75	-1.01	-0.74	0.31	-0.10
	Mean W.L. of the month	(m)					10.58	11.93	12.05	12.80	13.80	14.55	14.23	14.33
		1996	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Pumping rate (Daily average)	(m3/day)	1985	2177	2388	2668	2191	1050	1075	3337	3095	2715		
NJD1	Difference in M.W.L. from the previous month	(m)	-0.41	-0.53	-0.97	-1.21	-0.81	-0.63	-0.74	-1.46	-1.33	0.18		
	Mean W.L. of the month	(m)	14.56	15.09	16.06	17.26	18.11	18.74	19.47	20.94	22.27	22.09		
NJD3	Difference in M.W.L. from the previous month	(m)	-0.30	-0.66	-1.03	-1.18	-0.81	-0.44	-0.69	-1.51	-1.33	0.19		
	Mean W.L. of the month	(m)	14.64	15.30	16.32	17.51	18.32	18.76	19.45	20.96	22.29	22.10		

Fig. 3.4.2 Drawdown - Pumping Rate (Jun. 1995 - Oct. 1996)



3.5 Meteorology

3.5.1 General

Farm climate has two major aspects, viz (1) Macro-climate of the geographical region, depending mostly on latitude, altitude, mountain barriers, and distance from the sea; (2) Micro-climate of the location, depending mostly on wind and exposure to the sun. To observe and characterize the prevailing climate conditions, the meteorological observations were carried out at two meteorological stations in the Nejd Region, one at NARS [Altitude: 283.10m; Latitude 18°19'N; Longitude 54°03'E] and the other at Dauka [Altitude: 213.70m; Latitude 18°40'N; Longitude 54°04'E], and these weather stations were established by JICA in 1987 and 1988 respectively.

Observation and monitoring works at these two meteorological stations were restarted since the resumption of the Study in April 1995, with technical contributions from JICA in the form of necessary equipment, recording charts and other necessary materials. Since then most of the efforts and works are concentrated in instructing the new staff for efficient observations at these stations. Apart from these, in Nejd, there are two other meteorological Stations at Salalah [Altitude: 21.78m; Latitude 17°03'N; Longitude 54°08'E] and Thumrait, [Altitude: 448.0m; Latitude 17°40'N; Longitude 54°02'E], which are regularly monitored by the Ministry of Communications.

(1) Monitoring and Maintenance Works at NARS

From April 1995, the daily monitoring and maintenance works were regularized and have been carried out routinely, except on certain occasions. Both of the Department of Irrigation and the Department of NARS are in charge of the operation and maintenance works.

Data compilation work was concentrated to the recent charts from April 1995, while conducting the daily maintenance works. More development of human and technical resources is required for more efficient meteorological observation, compilation and chart reading.

(2) Climatological Data

Even though, the series of data collected is not sufficient enough to describe the climatological characteristics of the Study Area, maximum efforts were made to analyze the micro-climate variations in the Study and for comparison of these characteristics with that of the nearby areas.

This clause includes meteorological characteristics which were observed during this Work-III stage with utilized observation equipment which were installed by JICA during Phase-I Study. Observation items at each station are summarized in Appendix-5. During this Work-III stage, most of the works were concentrated to re-establish the proper works by the new staffs at the site.

3.5.2 Climatological Conditions

(1) Air Temperature and Relative Humidity

According to the comparison of temperature between Salalah and Thumrait, with the long term average record and the records of 1995 and 1996, it can be said that both the years 1995 and 1996 have had ordinary temperature conditions. Even though the annual average temperature is about 26°C at both the places, annual fluctuation among monthly average temperatures is different by 6°C at Salalah and 14 °C at Thumrait. The fluctuations at Thumrait might be due to its inland geographical location. Especially during May to September, an intense hot season, days with more than 35°C appear continuously.

Temperature and Humidity are new observation items with an automatic hygro-thermometer at NARS, since the resumption of the Study in July 1995. As presented in Table A-5.3.1, the coldest month is February (22.7°C), while the hottest month is August (32.0°C), with the fluctuations of about 10°C during one year observation period. At some time in August, the highest temperature of 45°C was also recorded. Regarding intra-monthly temperature fluctuations, the difference between daily maximum and minimum temperatures in summer season is higher with 15°C while it was about 10°C in the winter season. The difference in hourly maximum and minimum temperature becomes about 20°C in summer and about 15 °C in winter season. Dauka, which is located 40km north of NARS, seemed to have slightly hotter season than NARS. These micro climate conditions might be attributed by altitude, the leeward and interior location of NARS from the sea and mountain range and also by the prevailing clear skies and dry atmosphere.

Observation of Relative humidity was commenced at the same time as temperature and about one year series was obtained (Table A-5.3.2). Comparison of relative humidity data recorded at NARS and others locations reveal that the humidity is getting more drier when moving in North direction, based on annual average data. The records at Dauka shows a more drier situation in Dauka than NARS. Monthly average humidity values fluctuate in a range of 30% and 60%, with +/- 10% deviation from a median value of 45%. However, it was not able to clearly point out seasonal characteristics due to the limited period of observation.

Based on the hourly data, it can be said that the humidity turns to be drier from dawn and reaches to the daily driest condition within about four hours then it reverses to humid gradually from evening. Maximum humidity over 90% have been recorded in the morning hours. Hence almost all the farms in the Study Area are adapting night water application to reduce evaporation losses.

(2) Wind

Wind is expressed in velocity/wind speed and wind direction and are observed at the Study Site using a vane type automatic recorder. The wind at the NARS site is affected by monsoon which comes from south-west to the south direction. Based on monthly average records, the most calm wind occurs in December (1.9 m/s) and becomes turbulent in July (6.4m/s). The windy season also coincides with monsoon period, which is from July to September. Generally speaking, the winds in non-monsoon season are relatively gentler. Annual average wind speed at NARS is about 4.0m/s while 3.0m/s and 6.0m/s at Salalah and Thumrait respectively (Table A-5.3.3), which indicates the influence of geographical characteristics of those locations on their wind characteristics. Winds at Salalah, which faces the coast and with a mountain stand behind the town, is more moderate than Thumrait, which is located at the opposite side of mountain foot. Besides that, winds at Thumrait blows faster than that at Salalah throughout the year and intensified hourly fluctuations are noticed especially in the monsoon season based on monthly average speed computations. According to the annual average speed of those three locations, the wind speed at NARS exceeds that of Salalah by 30% and slower than that of Thumrait by 30%. The same is true when comparing the gust wind speed recorded at these locations (Table A-5.3.4). The gust wind speed is about 4 times that of average wind speed at NARS while at Thumrait and Salalah it is 2.7 and 3.5 times respectively.

Wind direction is regarded as the direction from which the wind is blowing and can be expressed in degrees, measured clockwise from the geographic north or in terms of prevailing wind direction as N 0°, NNE 22.5°, NE 45°, ENE 67.5°, E 90° etc. Yearly prevailing wind direction at NARS is S which is more or less similar to that of Salalah - S, SSE and Thumrait - SSE (Table A-5.3.5). However, the intra-year variations illustrate a distinctive east directional wind from the month of October 1995 to February 1996. Based on the above facts, the wind characteristics at NARS can be summarized as follows

a) Average wind speed is slower than Thumrait but faster than Salalah
b) Effect of monsoon on wind speed seems to be moderate while passing though Thumrait
c) Seasonal fluctuation is from 2.0 m/s in winter to 6.5 m/s in monsoon period
d) Prevailing wind direction is South
e) As can be seen from the hourly wind data, in clear nights, the usual wind direction is North due to sea and land breeze effect.

(3) Solar Radiation

The estimated daily mean solar radiation from the recorded solar intensity using a solar radiometer is shown in Appendix A-5.3.6. The amount varies importantly with season and cloudiness. The mean daily solar radiation follow a cyclic pattern in which the maximum solar energy of 21.43 MJ/m^2 day was observed in April 1996 while the minimum of 14.66 MJ/m^2 day was estimated for December 1995 which is the coldest month. The heating of the earth's surface and subsequent evaporation losses are much higher in summer than winter. The actual sunshine duration (Table A-5.3.7) is shorter (10.7 h) in winter and longer (12.2 h) in summer owing to the presence convective cloud masses and Sun's inclination.

(4) Evaporation

The evaporation record in Salalah shows a clear difference between monsoon and winter which are 2mm/day and 10 mm/day, respectively. The evaporation in monsoon season is about 20 % of that in winter season. For Thumrait it is noticeable that the fluctuation through a year is opposite of Salalah, that is, the evaporation reaches to double of winter level. And annual evaporation at Thumrait (5,300mm/year) is about double of the value at Salalah (2,500 mm/year).

Even though, different type of evaporation pan is used in NARS, making the fluctuation pattern of evaporation is more or less similar to that of both Salalah and Thumrait (Table A-5.3.8). Cumulated value from Sep.'95 to Aug.'96 at NARS is about 3,900mm/year and it might be reasonable to assume an average value of 4,200 mm/year based on the relation between long term average value and 1995 record at Thumrait. This result should be verified through compiling the results of daily observation work at the site.

(5) Rain

There was only one event of rainfall in June during this study period. This event was caused by monsoon turbulence which covered from south Oman to the north.

Date	Time		Rainfall	Remarks	
June 11 '96	5:30	9:30	13 mm		
	12:00	17:30	20 mm		
	20:30	21:30	6 mm		
	23:00	23:30	4 mm	Daily total :	43 mm
June 12 '96	11:00	13:00	10 mm	Daily total :	10 mm
Total			53 mm		

3.6 Water Use

This section presents the results of monitoring works of irrigation application at NARS.

3.6.1 Schematic Diagram of Water Use in NARS

There are some water application systems in the NARS, Center Pivot System (30ha), Linear Movement System (18ha), Bubbler System (for wind break trees and fruits) and Drip System (for Vegetables). Multi-emitter system is used for irrigating tree irrigation and solar system is used for vegetable plot and potable water use. Currently, the record of water application was covered for all the systems, excluding drip system.

(1) Production Well

NARS depends on two production wells, namely NJD-2 and NJD-4. Both of the wells are pumping water from Aquifer-C and their total depth is about 350m from the ground level, which were constructed as test wells in Phase-I study ('86-'89). These wells are installed with submersible motor pump with well head arrangement. On-Off switching can operate at booster pump station remotely. The abstracted groundwater is conveyed and stored in 2,000 cu.m capacity reservoir. Dimensions of the production wells are summarized in Appendix-6.

(2) Water distribution system

Water distribution is operated at pump station, which has four booster pumps to supply the water to each demand. No.1, 2 and 3 are for both of center pivot and linear move irrigation system. They are operating those three booster pumps alternately. No. 4 is for bubbler irrigation system, which is for tree irrigation.

(3) Measurement of water use

Measurement is carried out as follows;

a. Daily abstraction volume is measured with flow meters at each well head.

b. Water consumption is recorded with flow meter, which is connected at outlet of distribution pipeline.

(4) Shifting of production pumps to a deeper depth

The most critical and worth notice topic of the study period was shifting of pumps to a deeper depth at both of the production wells against the water level draw down. Even though its earlier commencement was suggested in the Progress Report I (March 1996), the actual work was carried out on August 3rd and 4th 1996 with efforts by both departments of NARS and Irrigation. During June and July, '96, most of the activities were concentrated to arrangements to accelerate this pump shifting works. The results of the pump shifting work in shown in Table 3.6.1. While awaiting for the pump shifting work, intermittent irrigation was followed from the end of May to beginning of August, 1996.

Results of Pump Shifting Works

Descriptions	NJD-2	NJD-4
Well structure		
Total depth	350.00 m	350.00 m
Ground level	282.00 amsl	284.00 amsl
Top of 9 5/8" casing	54.55 m	33.64 m
Casing 9 5/8" upto	269.53 m	271.29 m
Previous condition		
Pump installation depth	25.00 m	25.00 m
Cut-off level	23.00 m	23.00 m
Pump Dia.	196 mm (7.7")	196 mm (7.7")
Total pump length	2028 mm	2028 mm
Revised condition		
Pump installation depth	50.00 m	31.00 m
Cut-off level	43.00 m	25.00 m
Pump capa.	60 lps. @40m H	60 lps. @40m H

3.6.2 Record of Water Application

Water consumption by center pivot, linear move and tree irrigation are recorded. Water consumption for irrigation (grass and trees) is recorded daily by the operators. The result of the record has been reported monthly to Department of NARS and analyzed by Irrigation Department.

Record of Water Application to Grass (Unit: mm/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Recorded consumption												
'94									6.6	10.9	7.9	7.1
'95	6.5	7.0	7.0	6.2	10.4	10.0	9.2	10.9	8.5	9.9	6.9	7.8
'96	6.3	7.1	7.7	8.8	7.0	3.7	3.6	11.1	10.7	8.8		

(1) Water application for grass

At first, water application was conducted at both of the Center Pivot irrigation and Linear Move irrigation area. (In May 1995, water application for the Linear Move area was suspended to decrease the water consumption since the rapid water level depression was noticed)

During the first year, water application was concentrated to supply sufficient water to recover the poor grass growing condition, which was caused with water shortage stress obviously.

Trial cultivation was started from March '96 by dividing the 30ha field into four blocks to compare the yield to be caused with water application difference. The four blocks were grouped into two fields as Block-B&C (high level block) and Block-A&D (low level field). Results of water application through field trials are shown in Table 3.6.3.

Difference of water application effected sharply on the difference of yield of April harvest. Yield of hay at Block-B & C was 6.56ton/ha and it was 4.45ton/ha at Block-A&D. Results at Block-A&D was decreased by 32% while the other block could keep its previous yield (harvesting at May '96). Intermittent irrigation effected on the yield drastically, during the period of waiting for the pump shifting work. It is clear that the water shortage stress caused this depression. However, recovery of the grass growth is rapid after restarting of continuous irrigation as explained in section 3.2.

Results of Water Application through Field Trials

Recorded consumption	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
'96 monthly average	6.3	7.1	7.7	8.8	7.0	3.7	3.6	11.1	10.7	8.8		
Application for Block-B&C			9.1	10.4	8.2	4.4	4.2	13.1	12.6	10.4		
Application for Block-A&D			6.3	7.2	5.8	3.0	3.0	9.1	8.8	7.2		

(2) Water Application for Trees

There are 3,618 trees in NARS compound, which consists of wind break tree (2798 Nos.), fruit trees (742 Nos.) and Date palm trees (78 Nos.). It was recorded that water application in 1995 was higher, whose monthly average varied from 88 lit./day/tree to 211 lit./day, while the original plan was 60 lit./day. It was found that these records were made without measuring returned water from outlet to the reservoir. A new flow meter was added and fixed on water supplying system in January 1996, which aimed to measure the flow to be conveyed to trees only. The records from January '96 indicates the following ;

a. Almost sufficient water was applied from January to April.
b. During June and July the application was decreased, because of insufficient water pumping from the production wells.
c. From August, sufficient application was made.

Summary of Watering for Trees in NARS

unit:lit./No./day

	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
'95					141.5	211.3	158.2	159.3	164.2	177.7	133.6	88.4	154.3
'96	66.0	64.0	45.2	51.9	47.6	28.3	26.2	56.9	81.1	53.5			52.1

Note : Daily application records are in Appendix
3,618 Nos was adapted to estimate the daily application per one tree.

(3) Intermittent water application to crops

Water levels at the production wells reached cut-off level (G.L. - 23.0m) on 28th of May and there was no way but to adapt intermittent irrigation while waiting few days for the water level recovery from previous irrigation. And it was the only one way to keep the grass survive while waiting for the pump shifting works at that time.

Watering during this period was carried out as one day irrigation after 2 days rests and this manner was continued by 5th of August. The applied water during this period was decreased to less than 30% of the requirements of the season. As described in section 2.2 of this report the grass growing condition has turned to be frail and yellowish and the water shortage condition effected to the hay production directly.

3.6.3 Estimation of Crop Water Requirement

(1) Estimation of potential evapotranspiration (ETo)

Progress of the climatological observation clarify the difference of climatological conditions between Thumrait and NARS site, as explained in the section 3.5.2. The difference indicates some possibilities to reduce crop water requirement at site which was estimated with Thumrait data in the previous study.

The up-dated potential evapotranspiration was estimated with available climatological data observed at the site (temperature is quoted from Thumrait data). The values fluctuate from 4.2mm/day to 10.4mm/day and the annual total value is about 2,800mm/year.

Potential Evapotranspiration (ETo) and Evaporation at NARS

Unit : mm/day

	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean	Max.	Min.	Annual
Eto at NARS with latest data																
ETo	4.9	5.4	7.6	8.1	10.3	10.1	10.1	10.4	8.7	7.1	5.1	4.2	7.7	10.4	4.2	2794.0
Ratio-1	1.2	1.3	1.8	1.9	2.5	2.4	2.4	2.5	2.1	1.7	1.2	1.0				
Pan Evaporation record at the site																
	6.4	7	10	13.6	14.1	12.3	13.1	14.2	13	10.5	6.9	5.4	10.5	14.2	5.4	3847.7

Note : Temperature at Thumrait, Wind speed at NARS

(2) Estimation of crop water requirement (ETcrop)

Crop water requirement ETcrop is estimated from ETo multiplying with crop coefficient (kc) which varies from 0.4 to 1.0 by crop (grass) growing stage. An estimation of ETcrop with kc-assumption as 0.85 is shown in the following Table. The net water requirement is estimated as 5.0mm/day as the minimum value and 12.3mm/day as the maximum value, and the annual total water requirement is 3,310 mm. This estimation is about 25 % smaller than the present application rate, which was estimated in the Phase I study with climatological data of Thumrait.

The results indicate that there might be a possibility to reduce the water application rate, but the continuous observation of meteorological aspects at least few years more and verification at field is necessary. Detailed discussion on approach to water saving at NARS are summarized in Appendix 6.1.5.

ETo and Crop Water Requirement

Unit : mm/day

Descriptions	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
ETo	4.9	5.4	7.6	8.1	10.3	10.1	10.1	10.4	8.7	7.1	5.1	4.2	2794.0
ETcrop Kc 0.85	4.2	4.6	6.5	6.9	8.8	8.6	8.6	8.8	7.4	6.0	4.3	3.6	2383.2
N.W.R (up-dated)*	5.8	6.4	9.0	9.6	12.2	11.9	11.9	12.3	10.3	8.4	6.0	5.0	3310.0
Present application	5.2	7.2	9.1	10.7	12.0	12.4	11.4	11.2	10.4	7.2	6.2	5.0	4429.7

Note : Irrigation efficiency = 0.72