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JOINT DUTCH-ISRAELI RESEARCH PROJECT

ACTUAL AND POTENTIAL PRODUCTION FROM SEMI-ARID GRASSLANDS - PHASE II (APPSAG II)

1977 - 1981

FINAL TECHNICAL REPORT AND ANNOTATED BIBLIOGRAPHY

presented to the
Directorate General for International Cooperation
(DGIS)
Ministry of Foreign Affairs
The Hague - The Netherlands
and the

Division for International Cooperation
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INTRODUCTION

Research in agricultural science aims to help the farmer increase or maintain profitable production under different environmental and socio-economic conditions. In many developed countries such research is being conducted intensively and many new options have been made available to the farmer. In developing countries, where agriculture is often practiced under marginal conditions, the problems of instability and low profitability that confront the agricultural community are very great. There, relatively little effort has been invested in systematic research on viable options. In recent years, such agricultural regions have been attracting increasing local and international attention. This interest was the background to a joint Dutch-Israeli research project on 'Actual and potential herbage production under semi-arid conditions' that was initiated in 1970 by Prof. C.T. de Wit, Agricultural University, Wageningen and the late Prof. N.H. Tadmor, Hebrew University of Jerusalem, at the request of the Directorate International Technical Aid (DTH, now DGIS) of the Dutch Ministry of Foreign Affairs. The broad aims of the project were: to study the factors determining the primary production level of natural pastures and crops under semi-arid conditions; to quantify as far as possible the relevant processes; to formalize the accumulated knowledge into tools suitable for extrapolation and application; to indicate ways and means for the improvement of agricultural production systems under these conditions.

These aims were achieved to a large extent and served as the basis for the formulation of follow-up projects carried out between 1975 and 1980, - P.P.S. near the southern border of the Sahelian region in Mali and FAPROCAF in the South of Peru. It was shown there, that the concepts developed within the framework of the project were to a considerable degree also applicable in a semi-arid region with substantially different environmental conditions. (F.W.T. Penning de Vries and A.M. Djitèye, Eds: La productivité des pâturages sahéliens. Une étude des sols, des végétations et de l'exploitation de cette ressource naturelle, Pudoc, Wageningen, 1982.)

Concurrent with the projects in Mali and Peru a second phase was initiated in Israel (APPSAG II) in order to examine production systems that could use advanced technology to improve the stability and economic viability of agriculture in marginal regions. The subjects studied in this phase included the processes relevant to primary production; application of the knowledge on primary production to the study of secondary (= animal) production; study of the implications of these results for the design and study of agricultural production systems; study of the interaction of the biological and edaphic processes with the prevailing socio-economic

environment; design of appropriate technology for livestock drinking water that links water supply to forage production so as to control pasture utilization and prevent overgrazing.

The progress made in the project from 1971 till 1981 has helped to define systems that can sustain significant increases in the level of primary and secondary production. Even though not all the elements of the environmental and biological processes that are relevant to these systems are fully understood, the results are promising and can already be applied where appropriate. Increased animal production has been achieved by the development of intensively stocked, integrated production systems based on nitrogen fertilization of pastures, flexible cropping strategies and judicious use of available supplementary feeds and agricultural waste products.

It is considered that at this stage, increased profitability of those systems is dependent not so much on the accumulation of more detailed biological knowledge as on the development and implementation of better management methods. Those would make possible the realization of the potential fertility of the livestock, reduction of death and disease losses, optimal use of pasture and supplementary feed and achievement of higher weaning weights. In crop management, integration of livestock presents difficult decision problems that have not yet been satisfactorily solved.

Dynamic simulation models, describing primary and secondary production have usefully served to integrate and quantify the present knowledge of the biological processes and provide a basis for the development of agro-pastoral production systems in the arid zone. These systems have been analyzed with a linear programming model that identified promising systems under changing environmental and socio-economic conditions. This approach can provide a useful tool for the formulation of possible courses of development under different regional constraints.

The results of this project should ultimately contribute to the establishment of alternative viable agricultural systems that will improve the living conditions for the local population, without endangering the sustained productivity of the area.

A large number of scientific papers, theses and reports have appeared as a result of this project or in relation to it. On the basis of these publications, the main results and conclusions are presented here together with an annotated bibliography. These summaries serve as the final technical report on the project to the Directorate General for International Cooperation (DGIS) in the Netherlands and to the Israeli coordinating agency - the Center for International Cooperation (MASHAV).

TRAINING AND INTERNATIONAL COOPERATION

Trainee program

One of the original objectives of the project was to provide a framework in which graduates and undergraduates from developing countries, could be involved in on-the-job training that would acquaint them with the conceptual ideas underlying the project, provide training in experimental design and methodology and lead to relatively rapid diffusion of results for application in other areas. Unfortunately this program was not sufficiently appealing to attract members of the intended group. The major reason seemed to be that practical experience gained in such a project, is not enough to improve the position of the applicant upon return to his country. That purpose is apparently served much better through participation in courses leading to a higher degree.

There were, however, many willing candidates for this program in the West Bank of the Jordan river and the Gaza strip. All of these were university graduates holding a B.Sc. degree in agriculture or a related field from one of the Universities in the neighbouring countries. They were employed in the project for periods varying between 6 months and 2 years. This implementation proved successful for both sides: in general the graduates turned out to be enthusiastic, interested and very devoted to the jobs carried out in the project, while the experience gained in this way proved to be an asset to them in finding a job after completion of their term in the project. Today, nearly all the former project employees are employed in the West Bank either in experimental stations, in the extension service, the educational system or regional planning. In these fields they have been able to apply their knowledge for the improvement of agriculture in the area. They have benefitted particularly from the practical experience they gained in the project and have been noted for the willingness and skill with which they handle research and extension problems in the field.

Considering the foregoing, it can be concluded that such a training program can serve a useful purpose, provided that it is not over-ambitious and is directed mainly to applicants who come from the region in which the project is implemented. Candidates could include technicans as well as potential research personnel.

Practical field work for students.

The project provided opportunities for practical field and laboratory training that were taken up enthusiastically by university students and student technicians. The university students were mainly from agricultural faculties in The Netherlands, Switzerland and Germany and the technicians ('analisten') were from the Institute for the Education of Technicians (STOVA) in Wageningen, The Netherlands. Generally they spent about six months on the project and were responsible for a section of the work. Most of the participants indicated that their stay was a very valuable experience.

Post-graduate studies

The project provided for a number of M.Sc.and Ph.D. students, but despite a fairly large number of applicants only a few were found to be suitable. Four M.Sc. and two Ph.D. students were eventually supported by the project on a full-time basis and two Ph.D. students on a part-time basis. One student submitted his thesis to the University of Sydney, Australia, and the others to the Hebrew University of Jerusalem.

Scientific cooperation

The cooperation between Dutch and Israeli scientists was very close throughout the project and included participation of Dutch research workers who were active in the Mali project. The Dutch coordinator who was responsible for the Israeli project provided a continuous two-way contact with the Mali project, and so made fruitful, if indirect, cooperation possible.

PARTICIPANTS

The following workers have cooperated in the research programme:

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Y. Ofer	(partial, harvester ant ecology)
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Y. Zuckerbrot *	(partial, discontinued)

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* These workers were on a full or partial salary from the project.

SUMMARY OF RESULTS

Many soil, plant and animal processes relevant to semi-arid agriculture and animal husbandry were studied in the framework of the project and a number of agro-pastoral systems were designed, implemented and analyzed. A separate study of a technology for stock drinking water collection in sandy areas produced an operative system that has not been tried previously. A detailed summary of the results is given below. The main results that could have the greatest impact on agricultural practice in these and similar regions can be summed up as follows:

- Pasture production on deep soils in the semi-arid region is often limited more by plant nutrients, especially nitrogen, than by available water.
- Fertilizer nitrogen applications can increase long term average primary production but also increase the amplitude of fluctuations in production between years. This increases production instability, especially in livestock systems dependent on pasture.
- Wheat grain production is dependent more on moisture availability and distribution throughout the season than on nitrogen availability.
- Production stability and long term profitability can be improved by integrating wheat cultivation and livestock husbandry.
- Integrated agro-pastoral production systems are well suited to utilize available agricultural waste products as well as concentrate feed to intensify production and increase profitability. Irrigation of wheat can also stabilize production but is feasible on a small scale only.
- Application of advanced technology can increase the economically feasible carrying capacity of the land from 2 to 3 sheep ha^{-1} and lamb production from 50 to 150 kg ha^{-1}. In integrated systems with additional feed inputs, mainly for lamb fattening off pasture, these numbers are close to 7 sheep ha^{-1} and 500 kg of lamb live weight ha^{-1}.
- Efficient management of integrated systems is a major element in successful utilization of regional resources. Improvements of management decisions and management performance in such systems is an important area for future study.

1. PRIMARY PRODUCTION

a. natural pastures

1. In the semi-arid Mediterranean region when annual winter rainfall exceeds 150 mm, primary production under natural conditions is limited

by nutrients, particularly nitrogen, rather than by insufficient moisture.

2. Application of nitrogen fertilizers may increase dry matter production up to 3 fold under favourable rainfall conditions. Nitrogen fertilizer applied in one year is often recovered over a number of growing seasons. Apparent losses appear to be negligible, possibly due to a priming effect that results in enhanced mineralization of soil organic nitrogen when fertilizer nitrogen is applied.
3. The rate of water loss from the soil by evapotranspiration appears to be very similar under fertilized and non-fertilized conditions. As a result the production per unit effective rainfall is increased by fertilizer application. The improvement is partly the result of lower evaporation losses from the soil surface and partly of higher transpiration efficiencies.
4. The spatial heterogeneity, reflected in microtopography appears to be advantageous in relatively low rainfall years. The uneven distribution of infiltration produces a heterogeneous vegetation, that results in higher yields per unit area than under homogeneous conditions.
5. Under identical growing conditions, the rates of dry matter accumulation and transpiration of natural vegetation are similar to those of cultivated crops, such as wheat.
6. Whereas the production potential of the various species that comprise the natural pasture is very similar, their survival mechanisms are as variable as the plants themselves. This heterogeneity has in all likelihood been an important factor in ensuring continued production of natural pastures that have been grazed for more than 3000 years by small ruminants as well as by rodents and insects.
7. The highly variable environmental conditions from year to year are reflected in a changing species composition of the pasture. Some species are adapted to drought conditions and have a relative advantage in dry years. Other species, better suited to wetter conditions, dominate in favourable rainfall years. It is as yet not possible to predict the actual composition in any particular year from environmental variables only.
8. Studies on seed production have shown that the reproductive effort of most of the annual species is such, that when growing under undisturbed conditions, the ratio of reproductive biomass to total biomass is at least 0.15 and may be higher than 0.40, which is common for many cultivated species. In many cases a substantial part of the biomass is invested in protective and dispersal mechanisms rather than in seeds proper. It was established also, that a large proportion of the seeds is removed during the end of the green season and the

beginning of the dry season, especially by harvester ants *(Messor spp.)*. However, only in extreme cases is the seed available for germination in the following season a limiting factor for production.

9. The phenological development of the various species, characterized by the rate and order of appearance of vegetative and reproductive plant organs, is diverse. Both determinate and indeterminate flowering types occur. In both groups there are species differences with regard to onset of flowering. On the whole this seems to be due to different responses to temperature. Changes in photoperiod during the growing season appeared to be of minor importance. In the determinate group of species phenological stages from germination to maturity are particularly well related to accumulated temperature.

b. Winter grain crops

1. In the arable areas of the semi-arid region of Israel, wheat in virtual monoculture is the principal crop. This is so despite economic losses due to crop failure in dry years. These losses are covered by government subsidies as an incentive to farmers to maintain a relatively high level of inputs (fertilizer, cultivation) which ensures high yields in good years but are lost in drought years. No viable alternative system without livestock is available at present for the unirrigated lands. While the winter cereals can produce dry-matter yields similar to (or even higher than) natural pastures, their economic value is determined mainly by their ability to produce adequate yields of harvestable grain over a relatively wide range of conditions. Early season grazing, even in favourable rainfall years, reduces primary production but has a much smaller effect on economic yield. The grain yield is not only highly sensitive to rainfall amount and distribution but also to other climatic conditions, notably temperature at the time of seedfill in early spring. At that time of the year hot dry winds may occur in the Negev.These create excessive evaporative demands that cannot be met by the plants, and accelerate phenological development causing premature ripening and lower grain yields.
2. The interactive effects of water and nitrogen on grain yield in wheat, have been studied. It is clear that grain yield is much more sensitive to this interaction than is dry matter production. In fact, nitrogen fertilizer often had no effect on grain yields and even reduced them when at the same time dry matter production increased. This phenomenon, which is aggravated in drier years (and regions), is

related to more rapid water depletion and slower ripening rate in stands that have been given extra nitrogen.

3. On the whole, wheat/fallow rotation was economically inferior to continuous wheat over a four-year period. However, in other experiments in the region under somewhat drier conditions, wheat/fallow was clearly superior, presumably due to a better phyto-sanitary effect of the fallow on nematodes and soil-borne diseases. The carry-over of water from the fallow year to the subsequent wheat year, is generally insignificant but there is considerable carry-over of mineral nitrogen released in the previous season.
4. Nitrogen fertilizer applied to wheat is partially recovered by the plant and some can be found in the soil organic and mineral fractions. Between 5 and 15% appears to be lost in the first year after application as gaseous N in plots covered by plants. In fallow plots losses of applied nitrogen fertilizer appear to be greater. Fertilizer N application appears to increase mineralization of soil organic nitrogen ("priming effect").
5. Defoliation of the wheat during the first six weeks after emergence had a negligible effect on grain yield, but total dry-matter yield was reduced. The effect was similar in a drought year when grain yields were very low (up to 300 kg ha^{-1}) as well as in a good year when yields were 3000 kg ha^{-1}.

c. Sown pasture and forage legumes

Since legumes are able to fix atmospheric nitrogen in symbiosis with Rhizobium spp. their fertilizer requirements are restricted to the use of phosphorus. In addition they constitute high quality forage since their protein content remains high till late in the season. The abundance of native legumes in the pasture is low and erratic, but fairly extensive experimentation has been conducted with sown legume pasture and hay crops.

1. *Medicago polymorpha*, an annual medic has proven to be high yielding in normal and favourable rainfall years. When adequately fertilized with phosphorus its production is similar to that of nitrogen-fertilized natural pastures. The following characteristics have found to be important:
   a. Germination proceeds well but the initial biomass at emergence and the growth rates in the winter months are usually less than in natural pastures.

b. When late rains fall after a long dry break, it can provide a green standing crop up to one month longer than natural annual pasture species.

c. At low grazing pressures, *Medicago* pastures tend to be invaded by annual grass species which become dominant after 3 to 4 years. On the other hand fairly pure *Medicago* stands can be maintained for longer than 4 years if they are heavily and continuously grazed during the growing season.

d. If sown in mixtures with graminae, such as barley, the resulting sward is dominated by the grass and the legume is generally eliminated even when the pasture is heavily grazed.

e. On a dry matter basis, medic leaves have a crude protein content of up to 0.18 kg kg^{-1}, thus providing feed for grazing lambs equivalent in nutritive value to concentrate rations.

f. It is a multipurpose crop since it either can be grazed or, in favourable rainfall years left for hay making.

g. Even when heavily grazed, seed production is usually sufficient to provide spontaneous regermination the following year. This spontaneous regermination is an advantage since the seed is expensive (US$ 2 kg^{-1} at present). This virtually precludes its use as a one-season pasture in rotation with other crops.

2. Vetches grow well in favourable years, both as pure stands and in mixtures with barley and/or oats for hay crops. However, they have poor seed survival under grazing conditions, a characteristic that limits their usefulness in long-term annual pastures. Cultivation of vetch for hay in the region with less than 300 mm rainfall has been discontinued, as the fluctuating and generally low yields in most years cannot cover the cultivation and hay-making costs.

2. SECONDARY PRODUCTION

1. Awassi and German Mutton Merino breeds of sheep and crosses between them are particularly suited to grazing conditions in Israel. These breeds are relatively easy-care sheep with good mothering and strong new-born lamb characteristics. The German Mutton Merino is the only imported breed that has thrived as a pure breed both under grazing and handfed conditions.
2. Lambs of both breeds exhibit fast growth rates of up to 400 g of liveweight day^{-1} under favourable green pasture grazing conditions. According to European carcass grading criteria only the German Mutton

Merino can be classified as a top grade lamb. However, Awassi lamb is readily accepted in Middle Eastern markets.

3. Under grazing conditions with little or no supplementary feeding of the pregnant ewe, there is little twinning. 'Flushing', i.e. extra feeding before mating, will increase the prolificacy of Merino ewes but not that of Awassi.
4. Fleeces of 2 and 3 kg can be shorn from the Awassi and Merino, respectively. However, wool is not a major consideration since income from lamb sold for meat is much greater.
5. Both breeds suffer from external parasites and in their wake from fly strike. Hence, regular spraying or dipping is an essential routine, particularly during the summer months. Both breeds are also prone to internal parasites during the green growing season particularly at high stocking rates and must be treated shortly after entry into green pastures.
6. Finnish Landrace rams have been crossed succesfully with both Awassi and Merino ewes to increase prolificacy. The first generations of these crosses are prone to pneumonia but the disease becomes less important with successive generations. The lambs from these crosses do not exhibit hybrid vigour in their growth characteristics and have lower growth rates than either Awassi or Merino lambs. The crosses were originally envisaged for handfed intensive management. Under grazing conditions, survival of lambs in the first week of life has not been satisfactory. At pasture, the survival of lambs from multiple births requires intensive management to ensure adequate lamb birth weight and good mothering. Increased prolificacy involves extra expense in labour and feed. This is not always justified by the results.
7. Lambs from both breeds, weaned at 45 days of age respond to fattening with appropriate concentrate rations by achieving conversion efficiencies as high as 1 kg liveweight gain per 4 kg of dry matter ingested. The price ratio of 10:1 between lamb liveweight and concentrate, common under Israeli conditions, ensures the profitability of the fattening operation. Lambs weaned at over 45 days of age and at 15 kg liveweight when fed concentrate rations have a lower conversion efficiency, which may drop to 1:7. Fattening, however, can still be profitable if the liveweight to concentrate price ratio is higher than 10:1. As part of a grazing system, the lamb fattening component is profitable enough to pay for the extra costs of expensive supplementary feeding of ewes in adverse rainfall years.
8. Lambs weaned at 45 days of age and at 15 kg liveweight can gain over 200 g of liveweight day^{-1} from grazing green pastures, even in drought

years. In favourable rainfall years liveweight gains of 300 g day^{-1} have been achieved. These results were obtained at different grazing sites and from different pasture types in the northern Negev. Best results have been obtained in legume-dominant pastures, where stocking rates of 40 to 100 lambs ha^{-1} have been maintained, depending on rainfall quantity and distribution. In a good year lambs can gain up to 25 kg liveweight on pasture. In drought years with 150 mm annual rainfall, 10 kg liveweight gains were obtained.

9. Under drought conditions milk intake of sucking lambs can drop to 0.5-1.0 kg day^{-1}. These lambs will not put on weight under these conditions, but will develop normally when weaned after this period and put onto fattening rations.
10. Lambs weaned from ewes at pasture, reach 20 to 35 kg liveweight at 90 to 120 days of age. Liveweight at weaning is dependent on twinning rate, stocking rate and rainfall regime.
11. Observations on the grazing of sheep have shown that sheep rarely actively graze longer than 12 hours per 24-hour day. In general they appeared reluctant to graze at night; only when pasture herbage availability dropped below 500 kg ha^{-1} did grazing activity at night become necessary.
12. Death rates of both lambs and ewes recorded during the 4 year experimental period were higher than the 10 and 5% respectively, that are common under grazing conditions. This was due to the predatory activity of wild dogs, wild cats and wolves. Preventing this, necessitates the corraling of all classes of livestock at night behind animal proof fences.

3. INTERACTION BETWEEN PASTURE AND GRAZING SHEEP

Primary production and secondary production can be studied separately. However, in the final analysis the interaction between the growing pasture and the grazing animal must also be taken into account as it can determine the performance and the economic viability of agropastoral systems.

1. The Mediterranean climate and its associated annual vegetation, is particularly suited to the nutritional requirements of small ruminants. The lactation period of sheep and goats can continue up to six months and corresponds to the green growing season of the herbaceous vegetation in a good year. The dry summer vegetation provides adequate nutrition for dry pregnant sheep and seasonal deficiencies can be alleviated by relatively cheap supplements such as straw and poultry litter.

2. Most of the annual species that occur in the region are palatable to ruminants at some development stage. The nutritional value of the pasture varies widely within the season. It is high, with a digestibility close to that of concentrate feed shortly after germination and drops to the value of straw soon after maturity. It may also vary between years, even at constant stocking rates. The higher the primary production level, the lower the apparent digestibility.
3. The composition of the diet of the animals at any moment during the season depends on the relative abundance of the various species on offer. As this can vary from year to year, some species may be consumed when green in some years, whereas the same species may be left untouched until dry in years with a different botanical composition.
4. Sheep grazing year-round at stocking rates of up to 3 sheep ha^{-1} of nitrogen fertilized natural pasture, are able to meet their annual nutritional requirements with minimum need for supplementation, except in severe drought years. They are able to reach maturity, breed at 18 months of age and successfully raise lambs, with relatively small fluctuations in pasture and sheep performance between years.
5. Primary production is especially sensitive to grazing at high stocking rates in the early stages of the green season, when the growth rate of the vegetation is low. Consumption rates can then exceed the rate of dry matter accumulation, and lead to a constant low biomass with a consequent loss of production potential. It appears that in practice relatively early grazing is possible, because denser patches of vegetation are selectively grazed.
6. On natural pastures stocking rates as high as 10 ewes ha^{-1} can be achieved when annual rainfall exceeds 250 mm without significantly affecting primary production, provided:
   - the pasture is fertilized with nitrogen;
   - grazing is deferred after germination of the pasture and commences only after a critical biomass of 800-1200 kg ha^{-1} has been attained.

   Only in unfavourable rainfall years does such heavy grazing significantly reduce total primary production.
7. In studies with oesophageal fistulated sheep it was shown that the animals are able to select diets containing up to 6% more crude protein than the average herbage on offer. By inference from this, it may be assumed that they also select diets higher in digestibility than the average of the herbage on offer. This selectivity continues throughout the grazing year, as long as the plant material on offer is sufficiently heterogeneous. Sheep grazing wheat aftermath are better

able to maintain liveweight than sheep handfed the same material. This is probably also due to the ability of the grazing sheep to select material of higher quality, including fine material that is difficult to collect by hand.

8. Pasture continuously grazed during the green season has a higher nutritional value under moderate to heavy grazing than under light or no grazing. This occurs because grazing maintains a greater proportion of the biomass in a vegetative state. As a result a greater proportion of the biomass has a higher nitrogen content, lower fibre content and higher digestibility. This effect is carried over into the summer when the plants are dry. The physiological basis for this effect of defoliation is the increased tillering and branching with the consequent inhibition of fibrous stem and inflorescence formation. As a result translocation of protein to the seeds is delayed.
9. Grazing can play a positive role in the process of seed carry-over from one season to the next by promoting dispersal of seeds and enhancing their incorporation into the top soil layer, thus rendering them unavailable to ants. On the other hand, heavy grazing can reduce seed survival by removing protective litter. Soil compaction by sheep grazing when the soil is wet also reduces seed survival.
10. There seems to be no advantage in leaving large amounts of dry plant residues on the soil surface at the end of the year to promote germination or prevent serious run-off. In most years, no more germination was observed in plots in which dry plants residues were left on the soil surface than in areas grazed almost bare during the summer. However, heavy grazing in summer can produce a dust layer that is easily lost, together with much of the seed stock, during heavy storms (100 mm precipitation in one day!) that sometimes occur at the beginning of the rainy season. Germination then occurs mainly in large depressions where the eroded material was deposited or where dry residues prevented erosion.

4. AGRO-PASTORAL SYSTEMS

Nitrogen fertilization of natural pastures can increase production, but because annual rainfall is so variable, it also increases instability by causing greater fluctuations in primary production from year to year. Wheat cultivation is subject to similar instability, so that both systems on their own are uneconomical or at best marginally economical under current prices and production costs.

Animal production per unit area of pasture is primarily a function of production per animal and stocking rate, with the latter parameter

providing the main means of increasing production. Primary production from fertilized pastures can rarely be fully utilized in favourable rainfall years as stocking rates must be set fairly low so as to take into account production in bad years.

Stocking rates could be adjusted to favourable years by integrating pasture areas with wheat cultivation in an agro-pastoral system. Here, early grazing of young wheat, summer grazing of aftermaths, storage of straw and grazing of drought affected wheat would stabilize animal production at a high level and the additional income would offset the losses from wheat in bad years. Even here weaning weights would be dependent on current pasture conditions and in poor years would be too low to cover production costs of intensively stocked systems. A lamb fattening component can stabilize income provided the meat:feed price ratio is considerably higher than the feed:liveweight conversion ratio. As the former is 10-15:1 under current prices and the latter is generally less than 7:1 under current management practice, a fattening component is feasible at in the region.

To test this hypothesis three agro-pastoral systems in which a pasture replaced fallow in a wheat-fallow system, were designed for study from 1976/77 over a four year period. The agro-pastoral systems were:

A. Fixed ley. Half the land area was in fertilized natural pasture, the other half in wheat in a two year rotation with a sown legume pasture. This system was grazed by German Mutton Merino cross bred ewes (fertility 1.2 lambs ewe^{-1}). The area was divided into five sections, each section being grazed at a different stocking rate, which ranged from 3.3 to 15 ewes ha^{-1} of natural pasture.

B. Alternate ley. Half the area was in wheat in a two year rotation with a sown barley-legume pasture. This was grazed by German Mutton Merino X Finn cross bred ewes (fertility 1.8 lambs ewe^{-1}). The area was also subdivided into five sections, each section being grazed at a different stocking rate, ranging from 10 to 20 ewes ha^{-1} sown pasture.

C. Opportunistic system. Here, half the area was in wheat in a 5 year rotation with a sown medic-legume pasture. According to the rainfall year, the pasture was grazed by bought in weaned lambs at grazing pressures from 40 to 100 lambs ha^{-1}.

In all three systems there was a lamb fattening lot component. After 4 years of study, the results from the fixed and alternate ley systems, indicated that the optimum stocking rate in each system could be 10 and 15 sheep ha^{-1} of pasture respectively. Accordingly, from 1980/81, two semi-commercial systems were set up and were grazed at these optimum rates with flocks of 120 and 288 sheep respectively, in order to study management applications of these systems under more realistic farm conditions.

During the 6 years of the study 4 years were classified as drought affected, i.e. wheat yields were below the break-even yield of 1300 kg ha^{-1}.

The following results were obtained:

1. Continuous wheat and wheat-fallow grain yields per hectare gave negative incomes to labour and capital in 4 out of 6 years. Rainfall in 1979/80 and 1980/81 favoured relatively high wheat yields and resulted in positive, mean annual incomes of US$ 58 and US$ 46 ha^{-1} for continuous wheat and wheat-fallow systems respectively for the 6 year period.
2. Previous to this study stocking rates, in unintegrated systems, were maintained at 3.3 sheep ha^{-1} for most of the year with supplements of up to 70 kg of concentrates per ewe. In the fixed and alternate ley integrated systems studied, stocking rates from 3.3 up to 20 ewes ha^{-1} of pasture were maintained for 9 to 10 months of the year with supplements of up to 130 kg ewe^{-1} depending on the system and the rainfall conditions.
3. In the fixed ley system the mean number of lambs weaned per hectare, the mean weaning weight per lamb and the mean weaning weight per hectare over the 4 years ranged from 1.93, 31.3 and 60 kg at the lowest stocking rate (3.3 ewes ha^{-1}) to 8.8, 24.3 and 214 kg at the highest stocking rate (15 ewes ha^{-1}). In the alternate ley system the corresponding results ranged from 8.9, 21.7 and 193 kg (10 ewes ha^{-1}) to 17.8, 19.4 and 345 kg (20 ewes ha^{-1}).

   In the opportunistic system liveweight increase ranged from 10 to 20 kg $lamb^{-1}$ and from 400 to 2000 kg ha^{-1} of pasture respectively.
4. In all years lambs were fattened from weaning to a sale liveweight of up to 45 kg. In the fixed-ley system, annual total lamb liveweight sold ranged from 60 kg ha^{-1} in the lowest stocking rate to 272 kg ha^{-1} in the highest stocking rate. In the alternate ley system the corresponding results ranged from 370 to 710 kg ha^{-1}.
5. Integration of the income from wheat and lamb sales gave positive incomes to labour and capital in 3 out of 6 years at the optimum stocking rate (10 sheep ha^{-1}) in the fixed ley system. The mean annual income for the 6 year period was US$ 85 ha^{-1} of system.

   In the alternate ley system at the highest stocking rate (20 sheep ha^{-1}) there were positive incomes in all 4 years and the mean annual income was US$ 171 ha^{-1}. Only the 15 sheep ha^{-1} stocking rate was continued over 6 years. Here, there were positive incomes in 4 out of 6 years and mean annual income was US$ 99 ha^{-1}.
6. It was not possible to maintain the opportunistic system over the years because of the restrictions in buying and selling lambs imposed

by government regulations at the research farm. In the 2 drought years in which lambs were fattened on legume pastures at Migda and other northern Negev sites, indications were that net income per hectare of system could be a minimum US$ 300 without the feed lot component which would increase the income considerably.

5. SIMULATION MODELS

A number of simulation models were developed to study the relative importance (or sensitivity) of the processes involved in primary production under semi-arid conditions. They describe quantitatively the influence of various factors and their interaction. When sufficiently validated, these models may also be used to analyze environmental conditions and management manipulations. They can then also serve to apply the accumulated knowledge to problems in other regions with comparable conditions.

a. Primary production

Models were developed to describe undisturbed primary production. When nutrients (mainly nitrogen) were not limiting, the models produced satisfactory results over a number of seasons with very different climatic conditions. Where nitrogen was limiting, results were less satisfactory partly because of inadequate understanding of soil nitrogen dynamics. Where intake data were available, primary production under grazing could be adequately described.

1. ARID CROP-model of dry-matter production of annual pasture in semi-arid regions.

   ARID CROP describes the time course of plant growth in natural pastures if soil moisture availability is limiting primary production, but plant nutrients are freely available. The model was tested using field data from Migda measured during eight consecutive years. During this period weather conditions varied widely, including both rainy and drought years. Processes which had a significant effect on primary production were identified. Experiments were specifically designed and the results were used to improve the reliability of the model. The continuous development of the model has provided a useful framework for the design and organization of the research that was conducted in order to attain the objectives of the project. The model has also been applied with considerable success in the Mali project where it was possible to identify in a relatively short time the necessary adaptions, in plant physiological properties and soil properties that originate from differences in environmental conditions. The prediction

of biomass growth in the early part of the growing season is often poor because the processes that determine the early establishment of the pasture are difficult to quantify. These processes govern quantity, quality and distribution of the seed stock, as well as the germination characteristics of the different species. As a result the model has limited application to early season management problems.

2. PAPRAN-model of semi-arid annual pasture growth limited by both rainfall and nitrogen availability.

   This model is based on ARID CROP, but takes into account nitrogen limitation of growth. It also deals with plant morphology and seed formation, albeit in a highly simplified manner. It was difficult to obtain satisfactory results from this model mainly because of difficulties in describing the nitrogen transformations in the soil. Experiments were conducted to study some of these transformation phenomena in the field but they were only partially successful. Also plant responses to nitrogen deficiency are not understood well enough for reliable predictions.

3. WHEAT - a model to describe growth and production of spring wheat as governed by the availability of moisture and nitrogen.

   This model was developed to describe the wheat component of the agro-pastoral systems studied in the project. It is based on ARID CROP and PAPRAN but specific physiological properties of the wheat plant are taken into account. As grain production, rather than dry matter accumulation, is the prime objective of wheat cultivation, a rather detailed description of organ formation and inter-organ competition during the development of the crop was developed.
   The behaviour of the model shows satisfactory agreement with the real-world system, although the problems related to the description of the nitrogen cycle in the soil and the response of the plant to nitrogen deficiency remain a serious limitation to the application of the model. As the question of profitability of nitrogen fertilizer application under semi-arid conditions is controversial, this is an area for further research.

4. ARID CROP and PAPRAN have also been used to simulate primary production under grazing. Since it is difficult at this stage to describe quantitatively the relation between quantity and quality of forage on offer and intake by the animal, test runs were only applied in situations where animal intake was available from independent measurements.
   It was concluded from the results, that grazing can be described by the removal of green tissue, without any additional effect. The effects of possible selective grazing, i.e. complete preference for

leaf blades as compared to proportional removal of leaf blades and stems and sheaths were very small. This was not too surprising since grazing took place relatively early in the season, when stems constitute only a minor proportion of the total biomass available.

The heterogeneity of the vegetation in the field (patchiness) appeared to be of major importance in determining its response to grazing. The experimental results could only be explained by assuming that animal intake originated for the larger part from high-density spots in the field. These preliminary results indicate that the direct effects of grazing on primary production are mainly due to defoliation. For a full description of grazing systems it will be necessary to define in quantitative terms the relation between herbage availability, distribution and quality on the one hand and animal intake on the other. This is the well-known 'interface' between primary and secondary production.

b. Secondary production

1. Model of energy balance in sheep.

A set of equations to describe the energy balance of ruminants was developed by Blaxter and Boyne (J. agr. Sci. (Camb.), 90: 47-68, 1978) on the basis of the crude fibre, crude protein and gross energy content of feed and a curvilinear relationship between intake and performance. This approach was set up as a model of sheep liveweight gain and was tested against a varied set of experimental data. It was found to be satisfactory in predicting liveweight gain of lambs under both feedlot and grazing conditions provided there were no growth checks, due to sudden changes in diet. This model can be used as a component of sheep production system models.

2. Model of forage intake by grazing ruminants.

This model attempts to describe intake as a function of the behavioural characteristics of the grazing animals and the characteristics of the pasture. The amount of dry matter ingested at many moment is derived from such parameters as the searching rate of the animal, the frequency of encountering vegetation of a given density, the number of bites per unit time and the average size of the bites. These in turn are related to pasture attributes such as distribution of biomass height and density. It appears, on the whole, difficult to parameterize the model, since experimental work based on the above defined concepts, is relatively scarce. Some field observations have been collected, but the data base remains narrow. The main problem in incorporating the model in an interactive

animal-pasture simulation model is how to update the necessary pasture attributes (other than mean biomass) as a result of grazing.

c. Agro-pastoral systems

A number of models were developed to deal with management aspects of agro-pastoral systems from the point of view of the farmer and of the regional planner. These have not yet been fully validated but have been useful in organizing the accumulated knowledge into an orderly system and in analyzing some management and development problems.

1. MIGS 1 - Migda agro-pastoral system model.

This model describes an integrated sheep-wheat farm in the semi-arid zone. It includes the various biological components of the system, such as natural pasture, wheat, straw and grain, animal production, herd dynamics as well as management and economic components, such as feed supplementation, weaning, sale of lambs, ewe replacement in the herd, sale of wheat or straw. The model is planned to be used for the analysis of management options in such integrated agro-pastoral systems. It adresses mainly strategic decisions, such as the breed of animal to be used, the desired level of fecundity, the possible application of fertilizers etc. The structure is flexible enough to allow application to within - season management decision-making. An essential feature of the model is the accounting algorithm that is included, which translates the results of the biological components directly into relevant economic terms.

The model has not been validated but gives reasonable results. It has been run on a demonstration basis for the Midga-farm agro-pastoral systems and has been used to analyse actual weaning options in a drought year. The result of the analysis (late weaning) was opposite to what was thought to be the more advantageous practice (early weaning). Reconsideration of the problem showed the model result to have been correct.

As it is basically a management model using biological components in a highly simplified manner, MIGS 1 is not particularly dependent on detailed knowledge of physiological processes. It does need specific definition of the system components and local prices.

2. Management optimization models.

Towards the end of the project it became increasingly clear that implementation of the results to farm conditions creates new management problems. For some problems MIGS 1 could be used but it was also necessary to develop smaller more flexible models. Considerable progress in this direction has been made.

The approach adopted represents an intermediate stage between real-time interactive management models, that could be used directly by managers of agro-pastoral systems as an aid in decision-making and the total systems-model like MIGS 1. It is set up in modular form, each module defining criteria for a given management decision and applicable separately for a given situation. The complete set of models covers all relevant decisions within one growing season. These are mainly tactical decisions, that are taken within the season in dependence of and in response to the behaviour of the system at the time. This group of decisions includes start-of-grazing-time, weaning-time, application of supplementary feeding etc. Such decisions obviously not only depend on the state of the system at a particular moment, but also on the available alternatives and the prospects for the future. These aspects are covered by the model.

Application of the model to a series of growing seasons, covering typical sequences of weather variability, may also provide results on which strategic decisions can be based. These include decisions such as the optimum combination of breed of animal, prolificacy and the overall stocking rate employed in the system. Once these characteristics of the system have been fixed, they can only be changed over a relatively long time-horizon and they will not react to short-term fluctuations in weather conditions or in the economic environment. In the long term, however, they can be adapted and the model may then provide criteria on which possible changes can be based.

3. Technology identification and selection model.

Implementation of technical innovation depends not only on its intrinsic advantages but also on the regional conditions in which it is to be used. As the purpose of this project is eventually to improve agricultural practice in semi-arid regions, it is important to know under what development and socio-economic conditions the results can be applied. In order to study this class of problems a model was developed that analyses technology diffusion in a regional context.

The model determines which combination of technologies over time will best achieve the objective function. This can be maximum returns on capital invested, maximum production per unit of labour, minimum unemployment etc. In the present study, maximization of consumption was taken as an appropriate objective. The relevance of new systems can be assessed in this way, as well as the relative importance of technical and socio-economic constraints on the development of the region.

A limitation for the use of the model at this stage is its relatively high running cost. For this and other reasons it has only been applied for one specific case study, related to the area in which the project was carried out. In comparison, however, to the investment related to regional development, the model costs form only a minor expense.

The results indicated that the most fertile breed of sheep, the Finn Cross would be selected only if labour was plentiful and cheap. The local relatively extensive breed, the Awassi, is maintained over a long period even when meat:grain price ratios are high. For most scenarios, the German Mutton Merino is the preferred breed and is best managed at a relatively high level of intensity. High meat prices did not result in massive transfer to confined, intensive husbandry, but increased the use of improved pasture rather than wheat on cultivable land.

Comparison of model output with actual practice in the region indicated that less sheep than predicted are maintained on cultivable land. This is apparently due to inflexibilities that stem from government land policy and the social structure of the settlement organizations.

6. STOCK WATER DEVELOPMENT

In many areas of the world, range utilization by grazing animals is limited by lack of stock drinking water. In extensive sandy areas in the Sahel (and other parts of the world) drinking water is a problem because all precipitation infiltrates into the soil. Drinking water could be provided from artificial wells, that reach into the groundwater table. These are, however, expensive since the water table is generally several hundred meters below the surface. Moreover, they present an ecological danger, since continuous presence of drinking water may lead to over-exploitation of the vegetation with deteriorating effects on sustained productivity in those areas within walking distance of the well.

An alternative approach, elaborated in the framework of the project is the collection of part of the precipitation by means of an artificial impermeable subsurface layer, laid out under a slope. During rainstorms, water is collected on this layer and drained off through a drainage pipe to a plastic-lined, sand-filled reservoir. In the centre of the reservoir a tubewell is installed, to which 6-8 drainage tubes are centripetally connected. Water can be withdrawn from this pipe by hand or by small pumps. It has been shown, that the collection-efficiency is between 50-70%, depending on rainfall intensity and time-lapse since the previous rainfall

event. Storage efficiency approaches 100%, i.e. there is virtually no loss from the sand-filled reservoir, due to the protecting effect of the upper sand layer. Advantages for application are, that apart from the top of the iron tubewell no material is exposed, and so the risk of damage is diminished; all necessary operations can be carried out by hand labour, and this decreases investment costs; the amount of water collected is directly proportional to rainfall, which also governs forage production so the risk of overgrazing is small. In this way new areas, hitherto unaccessible to grazing due to lack of drinking water may be opened up for exploitation. Adjustments of the dimensions of the system presently in operation that may be necessary to meet requirements for drinking water of grazing animals (particularly cattle) in areas with different environmental conditions still have to be worked out. As the quality of the stored water is very good, this system can also be used to provide water for human consumption.

A preliminary analysis showed that the total investment costs amount to $\pm$ US$ 2.7 m^{-3} of stored usable water, for a reservoir with 150 m^3 storage capacity to $\pm$ US$ 2.4 m^{-3} for one with storage capacity of 600 m^3. Of this amount $\pm$ US$ 1.7 is needed for the collection system. The major components here are the plastic drain pipes (US$ 0.87 m^{-3}) which probably can be replaced by cheaper material like riverbed stones. For the tubewell in the actual reservoir, the iron piping that was used constitutes about half the cost. Replacement of the iron piping by welded drums seems feasible and would further lower the costs. The depreciation time of the system, with the materials being used now, is estimated at 20-25 years assuming no major mechanical disruption takes place. Again, the economics in terms of marginal meat production have to be worked out.

Development of the theoretical basis underlying the flow of water in such restricted systems, would facilitate transfer of this technology to different regions. This has not yet been worked out, but there are good chances that this will be achieved in the near future.

ANNOTATED BIBLIOGRAPHY

This bibliography is arranged in alphabetical order. It includes papers and reports that were published within the framework of activities funded, wholly or partially, by the project. It also lists relevant material written by researchers who were influenced by the project or whose work was relevant to the project and interacted with it. These 'spin-off' publications are marked with an asterisk (*). The super-scripted numbers refer to the sections in the summary of results.

Arnold, E., 1980[3]. Diet selection by oesophageal-fistulated sheep grazing in the semi-arid northern Negev (Israel). M.Sc. Thesis, Hebrew University, Jerusalem, Israel.

Sheep selective behavior, i.e., the chemical and botanical composition of their diet, compared to that of the pasture, was studied in a semi-arid Mediterranean range in the Negev Desert of Israel, with the oesophageal fistulation (OF) technique, during the years 1978 and 1979.

A point cover technique - calibrated by manual separation - was used both in the pasture and on extrusa subsamples placed in petridishes after the material was washed and diluted, to estimate the proportion of the various categories or species. Recovery of ingested feed, number of sheep and size of fistula, sampling dates and periods, preparation, classification and analysis of the extrusa material are discussed, as well as the possibility of using a microscope analysis technique that would allow examination of cuticula pieces found in faeces samples. This last possibility would obviate the need for the OF technique, which is difficult to maintain and with which sheep mortality is very high.

The present experiments show that sheep selectivity can vary between years: *Schismus* was selected in 1978 and rejected in 1979, according to the grazing situation; *Erucaria* was available in great quantities only in 1979 and strongly selected; dead material was present only at the beginning of 1978 and strongly rejected. *Hordeum* was usually rejected in both years. The selectivity (i.e., the intensity of selection) can vary between periods within the same year, and the category of forbs was even selected or rejected during different periods in the same year. Sheep do not seem to select specific sites in the field; the structure of the herbage appears to influence their selective behaviour. In 1979, the major part of the sheep diet consisted of leaves, but a certain amount of inflorescences (*Erucaria*, and *Schismus*, but never *Hordeum*) appeared in extrusa samples toward the end of the studied period. Sheep selected continuously a diet about 1% richer in nitrogen than the average of the pasture on offer (1979). It is

suggested that *Erucaria* was strongly selected because of its high nitrogen content, and possibly also because of its high moisture content. There were no differences between data of the same day for any of the categories. Between data obtained on different days within the same period, there were differences for a number of categories. Differences between sheep appeared in some categories.

Seed availability and consumption in summer 1978 were very low, and the disappearance of seeds in the sheep's digestive tract varied between the species (higher for *Hordeum*, *Koeleria* and *Phalaris* than for *Schismus*, *Erucaria* and *Anthemis*).

Arnold, E., 1980[3]. The digestion and viability of seeds consumed by sheep grazing annual pastures. Internal Rep., Botany Department, Hebrew University, Jerusalem, Israel.

This report describes the digestion of seeds by sheep grazing dry natural pastures after seed dispersal. Seed numbers, counted in oesophageal-fistulae samples, were compared to seed counts in faeces samples. The number of seeds found in both the diet and faeces samples were small, indicating the inability of sheep to collect seeds after seed dispersal by plants and the effectiveness of seed survival mechanisms. Only seeds of *Schismus arabicus* and *Erucaria boveana* were found in the faeces, the seeds of other species apparently being digested.

When seeds of species collected in natural pastures were handfed to sheep, seed numbers in faeces were small and restricted to the above mentioned species. Faeces incubated in the laboratory failed to produce seedlings. Apparently seeds consumed by sheep are either completely digested or loose their viability during passage through the digestive system of sheep.

Arnold, E., 1980[1]. Germination of natural pasture seeds under constant irrigation. Internal Rep., Botany Department, Hebrew University, Jerusalem, Israel.

In this study observations were made on the germination characteristics of species from the natural vegetation in the northern Negev under near optimum soil moisture conditions. Small plots were irrigated constantly for up to two months and seedling counts were repeated at short time intervals. Results are given of the waves of germination, the number of seedlings germinating and seedling biomass. Results from irrigated conditions are compared to those of rainfed controls.

In addition various methods of estimating both seedling number and biomass density are described and compared.

Barkai, D., 1979[2]. The effect of limiting milk and early weaning on the feed intake and energy balance of lambs from birth to slaughter. M.Sc. Thesis, Faculty of Agriculture, Hebrew University of Jerusalem, Rehovot, Israel.

In this study the effect of drought on milk intake of young lambs and their subsequent growth was simulated by limiting milk intake of individual lambs to a maximum of 1 kg of milk day^{-1}, during a 28 or 45 day period. Subsequently, lambs were either handfed a pure concentrate diet or were allowed to graze a legume pasture.

Liveweights of lambs after weaning from milk were only 5 to 10 kg, but they developed normally when fed concentrates and achieved marketable slaughter liveweights. Lambs weaned onto legume pastures also developed normally. The principal effect of restricted milk intake on subsequent lamb growth appears to be a lengthening of the time period needed to achieve marketable slaughter weights.

Barkai, D., E. Eyal and R.W. Benjamin, 1981[2]. The performance of weaned Merino x Finn lambs when fed concentrates ad libitum as a sole diet or when fed concentrates as a supplement when grazing dry pastures. Internal Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel.

Information is given on concentrate intake, growth rate and conversion efficiency of concentrate to liveweight gain of weaned lambs fed concentrate as a sole diet or as an ad lib supplement to their pasture intake. The time taken and the amount of concentrates needed to achieve a target liveweight of 45 kg are recorded. Concentrate intake per day and the conversion efficiencies of concentrate to liveweight gain are related to age and liveweight of lambs.

Conversion efficiencies of concentrate to liveweight gain were no more then 7:1, when lambs increased liveweight from 20 kg to a target weight of 45 kg. It is concluded, that under Israeli conditions, where the price ratio of concentrate to lamb liveweight per unit weight is 1:13 the fattening of lambs, weaned from grazing ewes, is a profitable enterprise.

Barkai, D., I. Noy-Meir, E. Eyal and R.W. Benjamin, 1982[3,*]. Early deferred grazing of natural pastures at high stocking rates in a semi-arid

Mediterranean environment. Internal Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel.

This paper examines the hypothesis that at high stocking rates on fertilized natural pastures, deferred grazing (sheep being fully handfed out of the pasture, from germination until availability of green biomass is sufficient) is economically preferable to continuous grazing with adequate supplementation in the pasture. In addition, information is given on the feeding behaviour of sheep, given access to both green pasture of low and increasingly higher availability and to a sufficient ration of supplementary feed. The pasture response to these treatments is also described.

The results indicate that continuous grazing, with adequate supplementation at a stocking rate of 10 sheep ha^{-1} is more economic in terms of short term meat production but less economic in terms of feed costs for all-year-round grazing. Adequate supplementation in the pasture effectively decreases grazing time and hence consumption of herbage, thus allowing the vegetation to achieve adequate growth rates.

Benjamin, R.W., 1980*. General report on the integrated management of pastures in the IVth region, Chile. Ministry of Agriculture, Centre of International Agricultural Cooperation, Rehovot, Israel.

In this report, methods of analysis and knowledge of biological processes obtained from 10 years of experience within the Dutch-Israeli project in Israel were used to describe, analyse and sum up agro-pastoral systems practiced in a semi-arid region of Chile.

Results of experiments carried out over a 4 year period, involving the establishment of shrubs in natural pastures, their management under grazing and their importance as a component of pastoral systems are presented. Special emphasis is given to the impact of recurrent drought and a stratified animal grazing system is described which, theoretically, could stabilize sheep numbers and income on a regional basis.

Benjamin, R.W., E. Eyal, I. Noy-Meir and N.G. Seligman, 1982[4]. Intensive agro-pastoral systems in the Migda Experimental Farm, northern Negev. Hassadeh (submitted) (Hebrew with English summary).

Wheat and fertilized pasture yields over a 20-year period were highly correlated with total annual rainfall, but yields of unfertilized pasture are only partly correlated. Regression analysis showed 'break-even' yields of pasture at 140 mm and of wheat at 240 mm. For the climatic conditions of

the study period wheat yields failed in 11 out of 20 years. Fertilized pasture yields are fluctuating with the total annual rainfall so that in both types of land taken alone, the production of marketable produce was highly variable from year to year. Integrated systems of pasture and wheat were planned to exploit the potential production of fertilized pasture and to reduce the production instability. These systems were managed at 5 stocking rates for 4 years and then at one, relatively high stocking rate for two subsequent years. All systems included a lamb fattening component to exploit the favourable meat: grain prices with the large number of lambs produced at intensive stocking rates. So in a sense, the systems were designed to produce a large number of lambs per unit area for fattening, rather than large amounts of weaned lamb per unit area. The value of production in the integrated systems ranged from US$ 667 to US$ 1840 ha^{-1} compared to a range of US$ 75- US$ 625 in the wheat only systems typical of the region. The gross margins ranged from US$ -82 to US$ 451 and from US$ -146 to US$ 402 respectively. The means for 6 years of intensive integrated systems at stocking rates of 5 to 7.5 sheep ha^{-1} were US$ 112 to US$ 140 compared to US$ 46 - US$ 58 ha^{-1} for wheat only.

The potential production from the integrated systems is considerably higher than that actually achieved because relatively complex integrated systems are sensitive to management level and management decisions. This seems to be a critical area for study in order to ensure successful abbliation of these systems on a wide scale. Nevertheless even at relatively low management levels, the intensive, integrated systems hold promise of increased economic production and greater stability. These systems remain profitable as long as lamb meat : grain price ratios are greater than 12 : 1. At ratios down to 10 : 1 the systems could remain profitable only with considerable increased management efficiency. Below these ratios extensive systems with much lower inputs per ewe would have to be applied.

Benjamin, R.W., E. Eyal, A.R. abu Arafe, A.M. abu Abed, C. Amar and G. el Rantisi, 1982[3]. The relationship between the milk and herbage intake of lambs at pasture. Internal Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel. (In prep.)

Measurement of intake of free-living animals is very difficult and estimates are difficult to verify. With lambs the difficulties are compounded, because of the two sources of the lambs diet: milk sucked from the ewe and herbage collected from the pasture.

An experiment is described in which total body energy of lambs is measured by a tritium dilution technique; milk intake is estimated by either weighing lambs before and after sucking or by a tritium turnover technique; herbage intake is estimated either by difference between total water turnover and water from milk intake, or by difference between total energy retention and energy intake from milk. Results indicate that herbage intake increases linearly with decreasing milk intake.

Benjamin, R.W., Y. Benjamin and E. Eyal, 1981[4,2]. Lamb production from the grazing of natural and sown-legume pastures in semi-arid and arid regions of Israel under commercial farm conditions in two drought years (1977/78 and 1978/79). Internal Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel.

The performance of early weaned lambs at several farm sites in the northern Negev during two semi-drought years is described. Stocking rates of up to 86 lambs ha^{-1} were applied, to utilize green biomass production during a growing season of up to 3 months. At these stocking rates, meat production per unit area is very high and it is shown that profits are higher under this type of land utilization than under others, traditionally practiced in the region. It appears that even in areas where the mean annual rainfall is 350 mm, fattening of lambs acquired from outside is more profitable than growing cash crops.

It is suggested that relatively small areas situated in more favourable rainfall conditions can be used to fatten large numbers of lambs, weaned from large marginal rainfall areas (spatial stratification). In this way limited input resources can be applied to small, potentially more productive areas that can be integrated with marginal areas to improve the overall productivity of a region.

Benjamin, R.W., E. Eyal and A.A. Degen, 1981[2]. Increasing the prolificacy of grazing sheep in a semi-arid region of Israel. Contribution No. 130 E, 1981 Series. Agricultural Research Organization, Bet Dagan, Israel.

This paper describes an attempt to increase the number of lambs born to Awassi and German Mutton Merino sheep, grazing in a semi-arid area. The experiment was designed to mate ewes as hoggets, to achieve two lambings per year and to increase litter size. Ewes were given hormone treatment to induce oestrus during the winter-spring anoestrus period. Results are compared to those of untreated ewes over a 3-year period and indicate that significantly more lambs can be obtained by the methods used in this experiment. Both litter size and number of lambs born to ewes in the flock

significantly increased to numbers similar to those obtained by these methods in temperate climates.

Benjamin, R.W., N. de Ridder and A.R. abu Arafe, 1981[3,2]. Grazing of dry annual summer pastures by sheep at a high grazing pressure in the northern Negev, Israel. Paper presented to European Sheep Breeders Association conference in Israel.

This study reports on the performance of sheep, grazing for up to 120 days on dry summer pastures. Liveweight, body condition, body composition, energy content and dry matter intake during the course of the experiment are given. In addition, details on mating and lambing the following winter are presented. Particular emphasis is given to the dynamics of biomass disappearance in grazed pastures. For this purpose, standing biomass is divided into three components, easily identified by eye estimation according to position in the canopy relative to the soil surface and ease of collection. These components are further subdivided into two fractions identified by their physical size. The quantity and quality of the various components was determined at various times during the experiment. Sheep performance is analysed in relation to the biomass characteristics.

Benjamin, R.W., N.G. Seligman and Y. Benjamin, 1981[2,5]. Simulation of the liveweight gain of animals using equations for a feeding system proposed by Blaxter and Boyne (1978). 1. Milk-fed grazing lambs. Internal Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel.

Equations for predicting the energy retention of ruminants, published by Blaxter and Boyne (1978), are defined in a simulation model to describe the growth dynamics of milk-fed lambs grazing green pastures. The predicted growth curves of lambs are compared to those measured in a published experiment describing the performance of lambs when handfed ewe milk at four different levels and either grazing green pasture or being handfed herbage, cut from the same pasture.

For some of the treatments the simulated values were very close to the measured ones but in others they deviated by up to 15%. It is concluded that under grazing conditions the simulation is particularly sensitive to correct classification of the nutritive value of the diet selected and consumed by the lambs.

Benjamin, R.W., N.G. Seligman and Z. Holtzer, 1980[2]. Liveweight and body composition changes of beef cattle grazing a dry summer pasture.

Internal Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel.

This study evaluates changes in liveweight and body composition of pregnant and empty cows, supplemented ad lib with poultry litter in a stocking rate experiment. Body composition was determined by a tritium dilution technique, before and after a two months grazing period. Despite large differences in available biomass between stocking rate treatments, changes in liveweight and body composition were similar.

Benjamin, R.W., A.A. Degen, A.R. abu Arafe and I. Noy-Meir, 1980[3]. Lamb and ewe intake in relation to biomass availability. Internal Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel.

This report describes an experiment to measure the milk intake of sucking lambs and the herbage intake of grazing ewes and their sucking lambs under conditions of varying green biomass availability.

Tritium dilution techniques were used to estimate the milk intake of free living lambs grazing with the mother ewes. This technique was calibrated against a gravimetric technique of weighing 32 lambs before and after sucking milk from their mothers, three times per 24 hours, under controlled conditions. These techniques and other methods to estimate intake are described and an assessment is made of their accuracy in relation to their use in grazing studies.

Benjamin, R.W., M. Chen, N.G. Seligman, D. Wallach and M.J. al Hadad, 1978[1,3]. Primary production of grazed annual natural pasture and of grazed wheat in a semi-arid region of Israel. Agricultural Systems 3: 205-220.

The effect of grazing on the above-ground primary production and water use of a fertilised annual pasture and of fertilised sown wheat was studied. Similar studies were made of the effect of cutting on sown wheat. Two simple models, one exponential, the other logistic were used to describe the primary production in all treatments.

The production of undisturbed pasture and undisturbed wheat was 6480 and 7080 kg DM ha^{-1}, respectively. Grazing had no significant effect on the total production of the pasture but reduced the dry matter yield of wheat by up to 32%. Cutting of the wheat reduced the yield by 56%. Water use was similar in all pasture and wheat treatments and was not directly related to production. The predicted production by both models was similar to

observation in the early part of the season but differed from observation in the later part. Possible reasons for the discrepancies are discussed.

Benjamin, R.W., M. Chen, A.A. Degen, N. abdul Aziz and M.J. al Hadad, 1977[3]. Estimation of the dry- and organic-matter intake of young sheep grazing a dry Mediterranean pasture, and their maintenance requirements. J. agric. Sci. (Camb.) 88:513-520.

The organic matter intake of two breeds of sheep grazing a dry medic pasture was estimated by five different methods. The methods used were the calibrated weight estimate for measuring available herbage before and after grazing; total faeces collection with a digestibility trial; a tritium dilution technique; an established ratio of dry-matter intake to water intake; and an estimation using established energy requirements and the estimated metabolizable energy of the pasture. All methods gave similar estimates. It was concluded that the tritium dilution technique was the most useful method and that the dry-matter intake to water ratio was the easiest technique to use. The relative merits of the different methods used are discussed. The maintenance requirements for grazing German Mutton Merino and Awassi sheep was found to be 0.64 MJ ME d^{-1} (kg $W^{0.75}$)$^{-1}$. For both breeds caged in an open field the maintenance requirement was 0.37 MJ ME d^{-1} (kg $W^{0.75}$)$^{-1}$.

Benjamin, Y., Y. Kali, E. Eyal, Y. Folman, D. Barkai and R.W. Benjamin, 1981[4,*]. The use of poultry litter as a supplementary feed for sheep. Internal Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel.

Experiments are described to determine the characteristics of poultry litter as a feed for sheep. Parameters of dry matter intake, digestibility, chemical composition and energy content of poultry litter are given.

The performance of sheep fed poultry litter in rations covering the requirements for maintenance, pregnancy and lactation is recorded. Results indicate that it is safe to feed poultry litter to sheep at a rate of up to 500 g day^{-1}. At this rate of supplementation sheep can maintain body weight, when grazing wheat stubble or when handfed wheat straw in barns. Additions of up to 400 g of corn meal to the above ration provide an adequate ration for sheep in late pregnancy and early lactation.

Chen, M., 1976[2,3]. The water turnover of sheep as a measure of their dry matter intake. M.Sc. Thesis, Faculty of Agriculture, Hebrew University of Jerusalem, Rehovot, Israel.

This thesis describes a study on the relationship between water turnover and dry herbage intake in individual sheep under controlled conditions. Analysis of the results shows a direct linear relationship: each kg of dry matter consumed requires a consumption of 3.2 kg of water.

Water turnover of sheep was estimated by a tritium dilution technique. Results were calibrated against actual water intake and a procedure for estimating the herbage dry matter intake of grazing sheep is described.

Cohen, M., 1982[6]. A numerical model for water flow over a sloping impermeable layer to a drain as a basis of a rainfall harvesting system in sandy soil. M.Sc. Thesis, Faculty of Agriculture, Hebrew University of Jerusalem, Rehovot, Israel. (In prep.)

This thesis gives a mathematical description of a water harvesting system for sandy soils in which water is collected on an artificial impermeable layer and stored in a sand trap well. The relevant flow equations are combined into a two-dimensional numerical model. Validation experiments, in which rainfall intensity, water flow, water storage and efficiency of the system were measured, are described in detail. Applications of the system to collect water for stock and human consumption are discussed.

Degen, A.A., 1976[2,*]. Physiological responses of native fat-tailed Awassi and imported German Mutton Merino sheep to desert conditions. Ph. D. Thesis, University of Tel Aviv, Israel.

The basic metabolic rates of two breeds of sheep, adapted to semi-arid environments were measured under controlled conditions. Responses of body temperature, panting rate, water intake, heart beat and water turnover to high summer ambient temperature under field conditions are described.

Particular emphasis is given to the water turnover of sheep under both caged and grazing conditions. Intra- and extra-cellular water spaces under conditions of restricted water intake are reported, together with water drinking habits and dry matter intake under a wide range of water intakes.

Dekker, C. den, 1980[3]. Botanical composition of annual Mediterranean pastures grazed at different stocking rates. Internal Rep., STOVA, Wageningen.

This report describes part of the results obtained in the study of vegetation dynamics in natural pastures in the northern Negev (cf. Loria, 1982).

Ellern, A., 1978[1,*]. Report of self-seeding annual pasture legumes in the northern Negev. In: Rapport d'activité No. 4., Mediterranean Pasture Working Group of F.A.O., Nyon, Switzerland. (mimeo-French).

Results of the performance of various self-seeding legumes, sown at different sites in the northern Negev, are tabulated and compared to results from the same range of cultivars, sown at sites in other countries, bordering the Mediterranean. Conclusions are that though some of the cultivars performed similarly at different sites, poor regeneration at other sites points to the need for improvement in plant material and methods of establishment.

Ellern, A., N.G. Seligman and J. Katznelson, 1980[1,*]. Self-seeding annual pasture legumes for semi-arid areas. Internal Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel.

The performance of 70 cultivars and species of pasture legumes, planted in small plots at three locations in the northern Negev, is described. Performance is evaluated in terms of cover, dry matter yield, earliness, date of flowering and yield of pods or fruits. Root nodule formation, deficiency symptoms, and regeneration characteristics are recorded. During the years reported, 1977/78 and 1978/79, which were drought years, none of the entries tested, was superior to the commercially available strain of .

Eyal, E., R.W. Benjamin and N.H. Tadmor, 1975[2,*]. Sheep production on seeded legumes, planted shrubs and dryland grain in a semi-arid region of Israel. Journal of Range Management 28: 100-107.

In this paper the results of a long term stocking rate experiment of sheep grazing three types of pasture with minimal supplementation are summarized. Higher lamb production was achieved from both the seeded legume and dryland grain pasture than from the shrub pasture. Only under extreme drought conditions was the shrub pasture marginally superior to the other pastures. Both, the legume and grain pastures gave higher lamb production than unimproved natural pastures, however, both the fore-mentioned pastures had the advantage of fertilizer application.

Feigenbaum, S.N., N.G. Seligman, R.W. Benjamin and D. Feinerman, 1982[1]. Fate of tagged fertilizer nitrogen applied to rainfed wheat growing under semi-arid conditions. S.S.S.A.J. (submitted)

The fate of fertilizer nitrogen applied to wheat growing on a deep loessial soil in a semi-arid region was studied with ^{15}N as KNO_3. The soil N was monitored at the end of the winter growing season and again at the end of the dry summer period. Nitrogen was applied at rates equivalent to 18 and 6 g m^{-2}. The wheat was grown in 1.25 * 1.25 m microplots and in 30 cm diameter plotlets enclosed by a hard plastic pipe, that was inserted 60 cm into the ground. The year was relatively dry with only 200 mm of rainfall, most of it early in the season. Late rains fell after the crop had dried and wetted the soil to below 60 cm.

Plant growth was less than average and N uptake amounted to 22-29% of the applied fertilizer. At the end of the summer 34-65% of the applied fertilizer N was detected in the soil as available mineral N. The amount remaining in the soil organic fraction was difficult to determine but appeared to be between 5 and 15%. Accordingly, gaseous losses amounting to 6-16% of the applied fertilizer must have occurred in the growing season, probably during relatively short periods after heavy rains in January and March.

Mineral N in soil and plant from non-fertilizer origin, amounted to 12-17 g m^{-2} in plots where N was applied, compared to 9.5 g m^{-2} in the control plots. The difference is apparently due to a priming effect.

Nitrogen loss from plots with no plants on them was very considerable (up to 30%). The reason for such a high loss (compared with losses in the plots with plants), is not at all clear.

Hochman, Z., 1982[1,5]. Effect of water stress with phasic development on yield of wheat grown in a semi-arid environment. Field Crops Research 5: 55-67.

This paper presents the results of an experiment in which irrigated wheat crops were subjected to severe soil moisture stress at three ontogenetic stages in the field in the Negev desert, Israel. Quantitative relationships were obtained for leaf water potential as a function of relative available soil moisture in the zone of root penetration and potential transpiration and for leaf diffusive resistance as a function of leaf water potential.

Stress from tillering to anthesis reduced leaf area index and grain number. Grain yield was 28% lower than in the unstressed treatment in which grain yield was 779 g m^{-2}. Stress from booting to grain filling resulted in reduced grain number and 1000-grain weight. Grain yield was reduced by 36%. Stress during grain filling reduced the 1000-grain weight and grain yield was 16% below the well-watered control.

Harvest index was unaffected by any of the stress treatments. Water use efficiency was reduced by stress and was lowest for stress between booting and grain filling.

The results of this experiment emphasize the dynamic response of a wheat crop to its water status. Especially significant in a semi-arid environment is the increased sensitivity of leaf water potential to soil moisture deficit during the linear phase of grain filling. This undesirable response could be remedied by selection for varieties which are less sensitive to soil moisture deficits during grain filling.

Hochman, Z., 1979[1,5]. Wheat in a semi-arid environment: A field and simulation study of the effects of water stress on yield. M.Sc. Thesis, Faculty of Agriculture, University of Sydney, Australia.

The effects of water stress on wheat (*Triticum aestivum* L., cv. Lachish) were measured in a field trial at Sde Boker in the Negev desert, Israel. Four treatments were imposed: 1. Optimal supply of water to the crop by irrigation whenever available water fell below 30% of its maximum, 2. Stress from tillering to anthesis, 3. Stress from booting to grain filling and 4. Stress during grain filling. Stress was discontinued whenever leaf water potential (LWP) at midday reached -25 bars and irrigation had been withheld for at least two weeks. Grain yields were: 779 $\pm$ 44, 559 $\pm$ 36, 498 $\pm$ 36 and 658 $\pm$ 28 g m^{-2} for treatments 1, 2, 3 and 4, respectively.

A mechanistic model of wheat production is described (viz. van Keulen & Seligman, 1982). The direct effects of soil moisture limitations on crop growth were accounted for by using relative transpiration (E/E_o) as a scaling factor on potential growth.

Comparison of measured and simulated results showed that the model's predictions of soil moisture and total above-ground dry matter accumulation were within or close to the experimental error for all treatments. Grain yield predictions were within experimental error for treatments 1 and 4. However, owing to 'residual' effects of water stress, which were not included in the model, yield predictions for treatments 2 and 3 were 36% and 24% higher than the measured mean. These differences were due to loss of apical dominance during pre-anthesis stress and incomplete recovery of LWP and leaf diffusive resistance, following the post-anthesis stress.

Kahn, H., Y. Benjamin and R.W. Benjamin, 1982[2,5]. Simulation of the liveweight gain of animals using equations for a feeding system proposed by Blaxter and Boyne (1978). 3. Concentrate-fed weaned lambs.

Internal Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel (In prep.).

This report presents and analyses the simulation of the liveweight gain of weaned lambs fattened with a concentrate ration. Data from experiments using lambs of different ages at different sites, are used. The Blaxter-Boyne equations were applicable when used to describe the growth of lambs from big sheep breeds, similar to those used in Great Britain, but for breeds such as the small Merino x Finn crosses, equations published by Australian workers yield better predictions.

It is concluded that the model may have useful application in indicating suboptimum management practices in lamb fattening systems under commercial farm conditions when lamb growth potentials are not realised.

Kahn, H., R.W. Benjamin and N.G. Seligman, 1981[2,5]. Simulation of the live-weight gain of animals using equations for a feeding system proposed by Blaxter and Boyne (1978). 2. Milk-fed grazing calves. Internal Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel. (In prep.)

Using data from a published experiment, this study compares simulated growth curves of calves with those measured. Deviations are minimal and it is concluded that the equations, used in the simulation model, are reasonably accurate for predicting the growth rate of sucking calves at pasture under well-managed farm operations. Large deviations, are to be expected, however, whenever management of the calf-cow-pasture grazing system is not optimal.

Keulen, H. van, 1981[5]. Modelling the interaction of water and nitrogen. Plant and Soil 58: 205-229.

In this paper several quantitative aspects of the interaction of water and nitrogen in plant growth processes are treated such as the relation between water use and crop production under different levels of nitrogen availability and the influence of soil moisture on nitrogen uptake by mass flow and diffusion.

A summary description of a simulation model is given, describing dry matter production under conditions where water and/or nitrogen may be limiting. The results of the model are compared to data collected in field experiments in the northern Negev desert. It is concluded that the model describes satisfactorily production at different levels of nitrogen availability, but that the uncertainty with respect to quantitative aspects

of soil nitrogen transformations, requires cautious use outside the calibrated conditions.

Keulen, H. van, 1981[1,5]. Modelling dynamic aspects of nitrogen in soils and plants. In: (J.M. Lyons, R.C. Valentine, D.A. Phillips, D.W. Rains and R.C. Huffaker, Eds.) Genetic engineering of symbiotic nitrogen fixation and conservation of fixed nitrogen, pp. 605-662. Plenum Press, New York, London.

A summary description is presented of a dynamic simulation model for the growth of natural pastures under limiting conditions of water and/or nitrogen. Special emphasis is given to the dynamics of nitrogen in the soil-plant system and it is concluded that many of the quantitative aspects are imperfectly understood. Consequently, descriptive and empirical formulations must be used in many cases, rather than explanatory ones. This limits the applicability of the model for predictive purposes.

It is shown, however, that reasonably accurate predictions can be given of the effect of nitrogen fertilizer application to natural pasture in the semi-arid northern Negev desert of Israel.

Keulen, H. van, 1980[1,5]. Modelling grain production of wheat under conditions of limiting water supply: a case study. Proc. 3rd Intern. Wheat Conf. Madrid, Spain pp. 414-419.

A simple model is described in which growth and production of wheat is related to the availability of water in the soil. Distribution factors for assimilates between various organs are introduced as forcing functions based on accumulated heat sums. Dry matter production at any moment is assumed to be proportional to the ratio of actual evapotranspiration to potential evapotranspiration.

The procedure is tested with data collected in an irrigation experiment in the Negev desert in Israel. It is concluded that the model description yields satisfactory results for water stress during the vegetative or the grain filling stage, but does not account for the effects of water stress during critical periods like fertilization or flowering.

Keulen, H. van, 1979[1]. Nitrogen nutrition, water use and plant production. Proc. 14th Colloquium, Int. Potash Inst., Bern. pp. 99-109.

In this paper the relation between plant production and water use is examined. It is shown that the relation between total annual rainfall and production is spurious because of the effect of rainfall distribution on

the partitioning between crop transpiration and losses by soil surface evaporation and the fact that indirect effects of rainfall, notably on the nutrient balance, are involved.

Water use efficiency, that is the amount of dry matter produced per unit water used is improved by adequate nitrogen nutrition. This is partly due to a more favourable transpiration to evaporation ratio, resulting from earlier soil cover. It may be partly due also to a greater transpiration efficiency. Experimental results of the assimilation/transpiration ratio under different nitrogen levels provide however conflicting evidence.

It is concluded that the importance of efficient water use in semi-arid regions warrants further research at the plant physiological level on the relation between assimilation, respiration and transpiration under various nutritional conditions.

Keulen, H. van, 1977[1]. On the role of nitrogen in semi-arid regions. Stikstof 20: 22-28.

It is shown in this paper that in semi-arid regions with winter rainfall, primary production is limited by moisture only at annual rainfall of below 150 mm. Above that value the natural fertility of the soil, especially with respect to nitrogen, limits plant growth and production. An inventory is made of the various processes playing a role in the nitrogen balance in semi-arid regions and quantitative estimates of the various terms on an annual basis are given.

On the basis of the estimates, a yearly balance is calculated, which provides the amount of nitrogen available to the vegetation, which in turn is 'translated' into dry matter production by assuming a limiting N-concentration in the tissue. Application of this balance to a 13-year period in the northern Negev in Israel shows reasonable agreement between predicted and measured peak biomass.

Keulen, H. van and N.G. Seligman, 1982[1,5]. Simulation of water use, nitrogen nutrition and growth of a spring wheat crop. Simulation Monographs, Pudoc, Wageningen. (In prep.)

This report presents a simulation model, that describes growth, dry matter production and grain yield of spring wheat and the possible effects of water shortage or nitrogen deficiency on production.

The main processes, incorporated in the model, CO_2-assimilation, transpiration, dry matter partitioning and phenological development of the crop are treated in detail and the data base is provided. The descriptions of the soil moisture balance and the soil nitrogen balance are similar to

those incorporated in other growth models for the semi-arid zone. Special attention is paid to the influence of microbial biomass in the soil on the nitrogen balance.

The model was validated with data collected in the northern Negev of Israel. Finally some other experiments from comparable regions are simulated as well, with reasonable success. The report contains a full listing of the model, written in CSMP III, as well as a dictionary and a list of relevant parameters and functions.

Keulen, H. van and C.T. de Wit, 1981[1,5]. Simulation of plant production in arid regions: a hierarchical approach. In: (D.W. Goodall and R.A. Perry, Eds.) Arid Land Ecosystems: Structure, Functioning and Management. Vol. 2 pp. 433-445. Cambridge Univ. Press.

A brief outline is given of the simulation model 'Arid Crop' for the prediction of dry matter production under conditions where water is the main limiting factor. Results of the model are compared to data collected for three consecutive years in the northern Negev desert of Israel and it is concluded that reasonably accurate predictions can be made.

It is argued that a hierarchical approach to model building, in which in each model one explanatory level is linked to one explainable level, whereas the results of such a model by means of functions or analytical expressions are incorporated in lower resolution models, provides a promising venue for systems analysis and simulation in agricultural systems. The principle is illustrated with the use of the transpiration coefficient as a link between a detailed model of crop photosynthesis, respiration and transpiration and the model 'Arid Crop'.

Keulen, H. van and C.T. de Wit, 1975[1]. Actual and potential herbage production in arid regions. Rep. Centre for Agrobiological Research (CABO) and Dept. of Theor. Prod. Ecol., Agric. Univ. Wageningen.

This report provides an annotated bibliography of phase I of the present project, which was executed between 1971 and 1975. Essential information of that phase is included in the present report, but the publications listed have not been repeated here.

Keulen, H. van, N.G. Seligman and R.W. Benjamin, 1981[1,5]. Simulation of water use and herbage growth in arid regions. A re-evaluation and further development of the model 'Arid Crop'. Agricultural Systems 6: 159-193.

This publication deals with simulation of plant growth under moisture limiting conditions. The original model was validated by using data from experiments during three growing seasons which were 'wet' years in that annual rainfall was higher than the long-term average for the region. Data from three subsequent seasons, which were characterized by either total rainfall lower than the average or by an unfavourable seasonal distribution, revealed a need for a re-assessment of the quantitative aspects of some of the processes described in the model. Major changes are connected with the partitioning of above-ground dry matter into leaves, non-leaf material and seeds; effects of prolonged drought on photosynthetic performance and accelerated plant death. The present description of the model gave satisfactory predictions of pasture plant growth for varying environmental conditions. A sensitivity analysis showed that the results of the model are not very sensitive to variations in weather parameters, except for amount and distribution of rainfall and, to a lesser extent, air temperature. It is concluded, therefore, that it may be applied with reasonable confidence, even when other weather data are only available from nearby locations.

Keulen, H. van, C.T. de Wit and H. Lof, 1976[1,5]. The use of simulation models for productivity studies in arid regions. In: (O.L. Lange, L. Kappen and E.D. Schulze, Eds.) Water and Plant Life. Ecological Studies, Analysis and Synthesis. Vol. 19: 408-420. Springer Verlag, Heidelberg, New York.

In this paper the use of systems analysis and simulation modelling for productivity studies in arid regions is illustrated, by presenting the model 'Arid Crop'. A brief description of the main processes incorporated is given and validation data are presented for the 1971/72 till 1973/74 growing seasons in the northern Negev desert of Israel.

It is concluded, that even when the nutritional status of the plants is eliminated as a decisive factor in plant growth under arid conditions, statistical analysis does not provide a sound basis for the prediction of yield in those regions. Simulation models seem much more promising for that purpose.

Lamers, A., 1980[3]. The above ground dry matter production of grazed and non-grazed crops within two agricultural-pastoral systems at Migda, Israel 1979/80. Internal Rep., STOVA, Wageningen.

Data on growth of wheat and barley under different dry-land conditions, are presented and analyzed. These data have been used to

facilitate current grazing management decisions and also for validation of crop growth simulation models.

Loria, M., 1982[3]. The effects of intensive sheep grazing on plant population dynamics and on vegetation composition in nitrogen-fertilized natural annual pastures in the semi-arid zone. Ph.D. Thesis, Hebrew University, Jerusalem, Israel. (in prep.)

Populations of the nine species which contributed most of the biomass at the Migda Experimental Farm were followed during three years in fields with three stocking rates (3.3 sheep ha^{-1} with continuous grazing, 10 and 15 sheep ha^{-1} with deferred grazing) and in small exclosures which were protected from grazing for various periods. The following measurements were made in quadrat samples: density of seedlings immediately after germination and a month later; density and weight of seeds produced and plant biomass at the time of seed maturation; density of seeds in the soil just after seed shedding, three months later, at the end of summer and after germination had been completed.

Large fluctuations within and between seasons were found in the population of each species and in its contribution to total plant biomass. The fluctuations in each of the major species could be related to its response to rainfall, competition and grazing.

A major proportion of seeds (80-95%) disappeared from the soil surface in the first three months after being shed, apparently due mainly to ant activity. Experiments with seeds placed on the soil confirmed that the maximum rates of seed collection by ants and the storage capacity of ant nests were sufficient to account for the observed seed losses.

The number of seeds germinating each rainy season is similar to the number of germinable seeds in the soil at the end of the dry season. This depends mainly on the number of seeds from last season's production which escaped ant predation by becoming buried in the soil. Sheep grazing reduces seed production of most species but the effects of trampling on seed burial in summer can increase germination density by reducing ant predation. Soil-surface compaction in winter tends to reduce the number of effective germination sites.

Loria, M. and I. Herrnstadt, 1980[1]. Moss capsules as a food of the harvester ant (*Messor spp.*). The Bryologist 83: 524-525.

Harvester ants, *Messor spp.*, were observed feeding on moss capsules in a winter when no other food sources were available. The ants climbed up the seta, gnawed off the capsules and carried them to their nests. In the

semi-arid region where this phenomenon was observed, suitable climatic conditions for spore maturation are rare, and feeding by ants on moss sporophytes even more strongly reduces reproduction by spores.

Loria, M. and I. Noy-Meir, 1980[1,*]. Dynamics of some annual populations in a desert loess plain. Isr. J. Bot. 28: 211-225.

This paper presents the germination, survival and seed production characteristics of annuals that were observed for two years in permanent quadrats, representing the vegetation of a loess plain in a 90 mm mean annual rainfall region. Only 45 mm fell in the first year and though germination was significant, survival and seed production were very low. In the second year, 155 mm of rain fell and germination occurred in a wider range of species; survival and seed production were high and almost all populations recovered their losses or exceeded them.

Different species appear to have different time-space patterns of germination, survival and seed production in different habitats. But nearly all the species studied appear to have a similar reproductive effort, about 50-60% of the biomass formed being apportioned to the seed and various structures of the fruit and inflorescence.

Noy-Meir, I., 1975[3,*]. Stability of grazing systems: an application of predator-prey graphs. Journal of Ecology 63: 459-481.

- 1976[3,*]. Rotational grazing in a continuously growing pasture: a simple model. Agricultural Systems 1: 87-112.

- 1978[3,*]. Stability in simple grazing models: effects of explicit functions. Journal of theoretical Biology 71: 347-380.

- 1978[3,*]. Grazing and production in seasonal pastures: analysis of a simple model. Journal of applied Ecology 15: 809-835.

Some simple mathematical models were developed, which express the dynamics of green pasture biomass as the balance between rates of pasture growth and animal intake, both of which are nonlinearly dependent on green biomass. Stability conditions were examined graphically and analytically, and time courses of biomass in different grazing treatments were obtained by simulation and by analytical-numerical solutions. The main prediction concerning semi-arid grazing systems is that if too high a stocking rate is applied when too little biomass has accumulated, the pasture will become locked in a state of low leaf area and low productivity for all or most of the growing season. Either a lower stocking rate, or deferment of grazing until a threshold of biomass proportional to stocking rate has been attained, will allow acceleration of pasture growth ('getting away') even

under grazing and realization of the potential seasonal production as determined by climatic factors. For instance, application to the Migda system suggests that at stocking rates of 10 ewes ha^{-1} or greater (such as used in N-fertilized pastures), deferment of grazing until 40-50 kg ewe^{-1} of dry matter in the green biomass has accumulated (equivalent to 400-500 kg ha^{-1}), is necessary to assure the pasture getting away.

Noy-Meir, I., 1979[3,5,*]. Graphical models and methods in ecology. In: (C.P. Patil and M. Rosenzweig, Eds.) Contemporary quantitative ecology and related biometrics. Statistical Ecology Series 12: 453-472. International Cooperative Publishing House, Fairland, Maryland.

This publication discusses the relationship between graphical and mathematical models. It points out both the advantages and the limitations of graphical methods and illustrates them by examples from two fields of ecology: in analysis of patterns of plant community composition by ordination and classification; and in graphical stability analysis. Conclusions are that graphical models which are precise, yet simple and not too abstract, are useful as didactic aids and often also as research tools. One of their main limitations is that graphic representation is limited to three dimensions.

Noy-Meir, I., 1982[3,5]. A simulation model of the herbage intake of grazing animals: A mathematical description of the processes involved in selecting, gathering and eating of herbage from growing pastures. Botany Department, Hebrew University of Jerusalem, Israel. (In prep.)

Models are available describing biomass growth of pasture and animal production after herbage has been consumed. However, little information on a quantitative basis is available concerning the dynamics of the herbage gathering processes of grazing animals. Consequently, no simulation model has been developed to describe these important processes.

This paper describes a simulation model, that is in the process of being developed, to examine the dynamics at the interface between pasture growth characteristics and the grazing behaviour of animals. Particular emphasis is given to that period in the pasture growing season, when herbage biomass availability is low and animal intake is below a satiation level.

Noy-Meir, I. and Y. Harpaz, 1977[1]. Nitrogen cycling in semi-arid agro-ecosystems in Israel. Agro-ecosystems 4: 143-167.

This study was conducted in the framework of a comparative study of mineral cycling in agro-ecosystems in various parts of the world. The nitrogen balance model developed by Harpaz (1975) was applied to calculate annual flows and storages of soil and plant nitrogen and of nitrogen-limited plant production. This was done for various agricultural systems in the semi-arid region, involving different utilization levels of plant biomass and of nitrogen fertilizer application.

Noy-Meir, I. and N.G. Seligman, 1979[4]. Management of semi-arid ecosystems in Israel. In: (B.H. Walker, Ed.) Management of semi-arid ecosystems. pp. 113-260. Elsevier, Amsterdam.

The land use and management of the semi-arid zone of Israel are reviewed in a historical context, distinguishing the following major systems: a) the old (traditional) crop-livestock system (Chalcolithic 3500 B.C. to Bedouin 1900), which combined partly opportunistic cultivation of barley and wheat with grazing by mobile herds of sheep and goats, used no irrigation water, fertilizer and supplementary feeds, and produced mainly for subsistence, b) recent modifications of the traditional system by Bedouins, due to social and economic changes, c) the modern continuous wheat cropping system, which uses high inputs of fertilizers and supplementary irrigation to obtain high grain yields, with little or no livestock grazing, d) new integrated cropping-grazing systems such as are being developed in the present project.

Ofer, Y., 1980[1,*]. The ecology of ant populations of the genus *Messor* and their influence on the soil, flora and pasture. Ph.D. Thesis, Hebrew University, Jerusalem, Israel. (In Hebrew)

The study was carried out in various pasture and field plots at Migda, where *Messor* ants are the major seed collectors. Density of ant nests was estimated. The number of ants per nest, amount of seed stored and seed storage capacity per nest were determined by excavation of some nests. There were large differences between 'small' and 'large' nests. The diameter of the 'threshing floor' was found to be a good indicator of nest size. Forage activity of ants in a *Medicago polymorpha* plot was observed and quantified. Though the ant foraging range was 25 m, a large proportion of the pods collected were from plants germinating on the threshing floor.

Soil measurements showed that the soil under ant nests and floors had a deeper moisture penetration, higher hydraulic conductivity, higher mineral N and higher P than the surrounding soil. The biomass and grain yield of wheat in a dry year were considerably higher over nests than in

surrounding flat areas and even somewhat higher than in depressions. Energy balance calculations were used in an attempt to compare the positive effects of ants on pasture production (local soil enrichment and concentration of rejected seeds on floors) with the negative effects (seed predation over the foraging range).

Penning de Vries, F.W.T., J.M. Krul and H. van Keulen, 1981[1,*]. Productivity of Sahelian rangelands in relation to the availability of nitrogen and phosphorus in the soil. In: (T. Roswall, Ed.) Nitrogen cycling in West-African ecosystems. pp. 95-113. SCOPE/UNEP Intern. Nitrogen Unit., Royal Swedish Acad. of Sciences, Stockholm.

Annual productivity of natural rangelands with annual grasses in the Sahel is not restricted by the actual precipitation, but by the low fertility of the soils. Deficiencies of the elements nitrogen and phosphorus are predominant. Which of these two limits productivity most in a particular case, can be determined from their ratio in plant tissue.

Productivity and nitrogen uptake by the vegetation of natural pastures were studied in sets of fertilization experiments on different soil types. On the basis of their results, a static model is developed to predict nitrogen uptake and productivity of rangelands. Inputs for the model are the natural fertility of the soil, fertilizer application rate and its recovery fraction and the duration of the phase of vegetative growth. Little attention is paid to losses of N from the vegetation that may occur in the seed filling period and afterwards. Recovery of fertilizer N was generally fairly high. In small areas and on special sites, denitrification and/or leaching may occur. On some overgrazed soils, low availability of P was found to limit N-absorption and thus plant yield.

Ridder, N. de, 1980[1]. Regrowth of some annual plants after a drought stress. Preliminary Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel.

This report describes the observed regrowth characteristics of plants that experienced a period of drought stress (severe enough to prevent plant growth and even induce leaf death) followed by rainfall adequate enough for possible resumption of growth. The vegetative regrowth patterns were found to vary among species: small grass species retillered from below the soil surface; tall grass species formed new branches at nodes high in the canopy, while intermediate types formed branches at nodes lower on the stem. This vegetative regrowth phase passed relatively rapidly into a reproductive phase.

Ridder, N. de, R.W. Benjamin and H. van Keulen, 1982[3]. Dry matter intake of German Merino ewes as related to biomass availability in semi-arid annual pastures grazed during the dry summer months (In prep).

The results of an experiment are described in which German Mutton Merino ewes were allowed to freely graze stem-cured hay in both nitrogen fertilized and non-fertilized natural pasture fields over a 120 day grazing period. Measurements were made of biomass availability, subdivided into three fractions according to physical size; biomass quality; quantity and quality of sheep intake; sheep performance and body condition. Dry matter intake up to a 'satiation' level, was linearly related to reduced (rather 'effective') biomass availability, that is, the amount of fine, higher quality material as a fraction of total available biomass. The 'satiation' level is not related to maintenance requirements of the animals, but to the ability of the sheep to collect preferred material of higher quality (mainly higher protein and lower fibre contents). As a consequence digestible energy intake can be too low for animals to maintain their liveweight.

Ridder, N. de, N.G. Seligman and H. van Keulen, 1981[1]. Analysis of environmental and species effects on the magnitude of biomass investment in the reproductive effort of annual pasture plants. Oecologia (Berl.) 49: 263-271.

In annual pastures utilized for grazing, the amount and quality of the standing dry matter in the dry season is of importance for the performance of the animals. Often both characteristics decline at the end of the green season. It is shown that dispersal of the reproductive structures of the vegetation may be the main reason for this phenomenon. Determination of the reproductive effort of the annuals indicates that the proportion of their total production invested in reproductive tissue may be as high as that of cultivated species. It is shown that the proportion of seed to total biomass of annual species is closely related to nutrient (mainly nitrogen) transfer from vegetative organs to the reproductive organs in the period between flowering and maturity, when in most cases, additional uptake of nitrogen from the soil is negligible. The effect of environmental and genetic factors on these processes is discussed.

Seligman, N.G., 1977[4,*]. Agricultural technology in the semi-arid zone. In: (J. Schechter, Ed.) The Negev - a desert reclaimed (case study on desertification) UN Conference on Desertification, Nairobi, Chapter 3: 45-68.

Chapter three is a discussion of dryland farming systems that have developed in the Negev since 1948.

Seligman, N.G., 1976[3,7,*]. Systems of management of livestock and pastures in grazing trials. In: Improvement and utilization of grazing resources in Mediterranean-type climates. Proceedings of an International Seminar, Badajoz, Spain, 1975. pp. 172-180.

The planning of grazing trials is discussed in the light of a systems approach. The animal density and treatment interaction is a fundamental component of most grazing trials and the importance of including all feed inputs during the experimental period (and sometimes beyond) is stressed. Relevance to a real grazing situation is regarded as basic to the validity of a grazing trial.

Seligman, N.G. and G.W. Arnold, 1978[5,3,*]. Simulation of intensively managed grazing systems. In: (A.J. Breymeyer and G.M. van Dyne, Eds.) Grassland, system analysis and man. pp. 853-880. Cambridge University Press, England.

The structure and use of four simulation models developed to analyse intensively managed pastures are compared. It is concluded, that although some insight into the processes that govern such systems has been gained, the application of the models to research planning or farm management has been very limited. It is concluded moreover that future development in this type of simulation modelling can only be useful if it will be directed more specifically to pasture management problems that can benefit from such an approach.

Seligman, N.G. and H. van Keulen, 1981[5,1]. PAPRAN. A simulation model of annual pasture production limited by rainfall and nitrogen. In: (M.J. Frissel and J.A. van Veen, Eds.) Simulation of nitrogen behaviour of soil plant systems. pp. 192-221. Pudoc, Wageningen.

This model describes dry matter production of herbaceous vegetation for situations where either water or nitrogen may be the limiting factor. The structure of the model is based on 'Arid Crop' which considers only water as a possible constraint. To that model are added state variables and processes pertaining to the nitrogen balance in the soil and the nitrogen status of various plant organs (leaves, stems, roots and seeds).

The influence of nitrogen availability in the soil on uptake by the plants is taken into account, as is the influence of plant nitrogen status on dry matter production and partitioning of dry matter.

The model has been validated against a limited number of experiments carried out in the northern Negev in Israel. The results, when compared to the real-world system are rather variable. It is concluded that the model may be used with some confidence to predict fertilizer response of annual vegetation in winter rainfall regions, but that extrapolation outside the 'calibration area' should only be carried out very cautiously. One of the major problem areas is the quantification of processes related to soil nitrogen transformations, which are microbiologically based and which are very difficult to validate. It is surprising, that despite the enormous effort put into fertilizer research, relatively little information is available on instantaneous response of plants to nutrient shortage.

The model has served and continues to serve as an indicator of gaps in our understanding and therefore as an aid for the design of new experiments. As a management tool it is hardly applicable at this stage.

Seligman, N.G., R.W. Benjamin and E. Eyal, 1981[4]. Migda Systems. A model for studying management systems of an integrated sheep-wheat farm in the semi-arid zone of Israel. Special Publication No. 207, Agricultural Research Organization, Bet Dagan, Israel.

This publication describes a simulation model, developed to examine and analyse options for agro-pastoral systems designed at the Migda Experimental Farm in the northern Negev. The inputs and outputs of the model are both in conventional quantitative physical units and in monetary terms allowing an economic evaluation of the various management options.

The model is in the process of being validated but has been used to examine and analyse the economic consequences of different weaning options. It is at present being adapted as an aid for farm management decision-making on an 'on-line' basis. In that way the model will be used to examine the options availabe to a farmer in the event of an expected but unpredictable occurrence, such as drought.

Seligman, N.G., R.W. Benjamin and M. Yanuka, 1981[1]. The apparent recovery of fertilizer nitrogen applied to natural annual vegetation growing on a deep loess soil in a semi-arid region of Israel. Internal Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel.

This paper reports on an experiment carried out to test the hypothesis that nitrogen, applied to natural vegetation growing on a deep soil in a semi-arid region is eventually completely recovered in the biomass harvested, with no losses of mineral nitrogen from the system.

Nitrogen was applied at a rate of 160 kg ha^{-1} at the beginning of a three year period or as three equal annual applications. Apparent nitrogen recoveries in the harvested biomass, relative to a control, were almost 100% for both application methods. This result, combined with the analysis of soil samples indicated that there had been no significant losses of mineral nitrogen from the system during the three growing seasons. The possibility that more nitrogen was mineralized in the fertilized plots, was not examined.

Seligman, N.G., H. van Keulen, A. Yulzari, R. Yonatan and R.W. Benjamin, 1976[1]. The effect of abundant nitrogen fertilizer application on the seasonal change in mineral concentration in annual Mediterranean pasture species. Preliminary Rep. No. 754, Division of Scientific Publications, The Volcani Center, Bet Dagan, Israel.

The aim of this study was to obtain preliminary information on the effect of adequate nitrogen nutrition on the mineral and nitrogen concentration in a number of annual native pasture species, during the growing season. Seasonal changes in total nitrogen, phosphorus, potassium and nitrate nitrogen are presented graphically for both nitrogen fertilized and non-fertilized fields.

Only small differences in nitrogen concentration were measured in plants from nitrogen and non-nitrogen fertilized pastures due to the overriding effect of nitrogen dilution in plants resulting from rapid growth of swards and accumulation of structural tissue. A clear effect of fertilizer application was detected only in grass species.

Shanan, A., R.W. Benjamin and N.G. Seligman, 1981[3,2]. Some observational studies of beef cattle grazing on dry summer pastures. Internal Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel.

The behaviour of beef cattle, grazing at three different stocking rates and supplemented ad lib with poultry litter, was observed over a two months period. Water intake and poultry litter consumption were recorded and related to grazing time. Grazing time was inversely related to stocking rate, cows at higher stocking rates compensating for shorter grazing times by consuming more poultry litter. It was concluded that poultry litter,

given as a protein supplement to grazing cows when grazing dry pastures, is also an important source of energy, when pasture availability is low.

Shanan, L., J. Morin, M. Cohen and D. Rosenzweig, 1980[6]. Harvesting rainfall in areas with sandy soils using a buried plastic membrane. Preliminary Rep. No. 783, Division of Scientific Publications, Volcani Center, Bet Dagan, Israel.

In this report materials, methods and details of the construction of a rainfall harvesting system for sandy areas, are described. Preliminary results from simulated rainfall trials, using three types of selected membrane collectors, are presented with hydrographs to illustrate the performance of the collectors.

A mathematical model describing the processes involved was developed and used to predict the performance of the collectors. Computed water yields from rainfall events showed only small deviations from observed values.

Spharim, I. and N.G. Seligman, 1982[4]. Identification and selection of technology for a specific agricultural region: A case study on sheep husbandry and dryland farming in the northern Negev, Israel. Agricultural Systems (in press).

In this publication natural and socio-economic constraints on the selection of existing and potentially available farming technologies are analysed for a particular agricultural region. The development of sheep husbandry and wheat cultivation systems in a semi-arid agro-pastoral region in the northern Negev of Israel is used as a case study. The approach employed involves defining the input/output relations of a set of technologies based on wheat cultivation and on an increasingly intensive range of sheep production systems. The region is defined by its borders, land classes, physical and financial capital, available labour, plant and animal genetic stock and climatic conditions. An optimum mix of technologies over a development period of 15 years is then determined using a multiperiod linear programming routine. The technology assessment is then concluded by varying the future socio-economic scenarios of the region and analyzing the response of the model. In this study, the effects of labour availability in the region, meat:grain price ratios and wheat prices are dealt with in particular.

It is suggested that the approach used can serve a useful purpose in analyzing effects of socio-economic policy measures on regional technology

selection as well as in development planning. It can also provide relevant information for R&D project evaluations.

Summeren, D. van, 1980[1,3]. Effect of grazing and nitrogen fertilizer on the growth of a pasture composed of annual mediterranean species. Internal Rep., STOVA, Wageningen.

Data of above ground biomass in grazed and ungrazed swards of annual pastures at the Migda Experimental Farm are presented and analyzed. The data have been used for validation studies of simulation models (e.g. van Keulen et al., 1981).

Trouw, J.M., 1980[3]. The relationship between sheep performance and the rate of disappearance of a dry annual natural pasture, when grazed during the dry summer months. Internal Rep., STOVA, Wageningen.

This report contains a description and results of an experiment on summer grazing of natural pastures (cf. de Ridder et al., 1982).

Ungar, E.D., 1981[1]. Meteorological data booklet. Part 1. Months of October-April, 1962-1980. Division of Scientific Publications, Volcani Center, Bet Dagan, Israel.

Meteorological data, collected at the Migda and Gilat research stations in the northern Negev are tabulated in this publication. Daily values of total global radiation, maximum and minimum air temperature, dew point temperature at 800 and 1400 hours, wind run and rainfall are given for the growing season, which extends from October 1st till May 1st. The need for such systematic compilation of these data arises from the steady request by research workers for the meteorological characteristics of a particular growing season, and for use in simulation models to generate growth curves of natural vegetation and winter grain crops.

Ungar, E.D., 1981[4,5]. The application of simulation modelling to the study of agro-pastoral systems in a semi-arid zone. Internal Rep., Botany Department, Hebrew University of Jerusalem, Israel.

Three simulation models are briefly described: 'Arid Crop' and 'Papran' which simulate the growth of herbaceous annual vegetation when either soil moisture or soil nitrogen and soil moisture are limiting plant growth; and an agro-pastoral systems model that simulates meat and grain production from an ingrated wheat-pasture system.

The inter-relationships of simulation modelling activities carried out within the framework of the joint Dutch-Israeli project are illustrated. Particular emphasis is given to explaining the possible application of the agro-pastoral systems model to investigate the impact of various management options, such as land allocation between crops and pasture, stocking rate and animal supplementation policy on biological and economic performance of a system.

Ungar, E.D., 1982[4,5]. An application of simulation modelling to decision making in the management of agro-pastoral systems in semi-arid regions. Ph.D. Thesis, Botany Department, Hebrew University of Jerusalem, Israel (In prep.)

Chapters in this thesis, presently available, are:

1. A theoretical framework for the study of the management of agro-pastoral systems.

   This chapter explores the management implications of unpredictability in the determinants of system behaviour and attempts to arrive at an operational definition of strategic and tactical management decisions.

2. Management decisions in an agro-pastoral system.

   A list and description is presented of the major management decisions in a specific agro-pastoral system. Each decision is classified as either strategic or tactical.

3. The rational utilization of green wheat in agro-pastoral systems.

   In this chapter the importance of wheat in an integrated wheat-pasture system is examined. The consequences of alternative uses of wheat are explored using 'possible outcome analysis'.

4. Lamb production in an agro-pastoral system.

   A feature of this chapter is the presentation of a lamb movement matrix that defines possible flows between lamb-rearing and nutritional locations. From these locations are selected those that are feasible at a particular decision-making moment. This approach was introduced in order to eliminate the need to set a priori lamb-rearing decision criteria.

5. Application of the simulation model 'Arid Crop' to a hay production research problem.

   The model is used to investigate the possibility that a grain crop may sometimes be a viable option as a hay crop. Specifically, the possible advantages of late maturing varieties are explored by simulation to evaluate their potential usefulness before launching a plant selection program.

Ungar, E.D. and H. van Keulen, 1982[1,5]. The simulation model 'ARID CROP' in FORTRAN. Simulation Reports CABO/TT No. 1, Wageningen. (In press)

This report provides a complete listing of a FORTRAN-version of the simulation model 'Arid Crop', a list of parameters and functions used in the model with their numerical values and a complete dictionary. In addition, a summary description of the model and its main features is given. An example of job-control cards is provided for running the model on a CDC computer.

Ungar, E.D., H. Krussi, M. Loria and H. van Keulen, 1981[1]. The effect of germination date on development in annual pasture species of the northern Negev. Internal Rep., Botany Department, Hebrew University of Jerusalem, Israel.

This report describes an experiment designed to determine the factors that govern the phenological development of annual pasture species, such as temperature and photoperiod. Results showed a clear tendency for more rapid development with later germination. Graphical analysis indicated that plants may require a constant heat sum to reach a given developmental stage irrespective of germination date. Little or no photoperiodic effects could be demonstrated.

Wijnmalen, P., N. van Duivenbooden, A. Jeeninga and I. Olieman. 1979[1,3]. It's all magic. Internal Rep., STOVA, Wageningen.

This report contains results of experiments carried out in the 1978/79 growing season in Migda.

Yanuka, M., R.W. Benjamin and N.G. Seligman, 1981[1]. Strategy considerations in applying nitrogen to rotations of wheat growing in a deep loess soil under variable rainfall conditions in a semi-arid region. Internal Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel.

This paper investigates the consequences of applying nitrogen to continuously cropped wheat and a wheat-fallow rotation in a 4-year experimental period, in which drought years and relatively 'wet' years were experienced.

Dry matter production, grain yields, nitrogen uptake and inorganic nitrogen concentration in the soil profile are given and are used to

calculate the apparent recoveries of applied nitrogen and the mineral nitrogen balance. Results indicate that no significant amount of mineral nitrogen appeared to be lost from the system.

Yanuka, M., N.G. Seligman and R.W. Benjamin, 1981[1]. The effect of defoliation early in a growing season on the production of barley and wheat cultivars in a semi-arid region of Israel. Internal Rep., Department of Range Science, Agricultural Research Organization, Bet Dagan, Israel.

The effect of defoliation before booting, on biomass and grain yields of one barley and two wheat cultivars, sown at two densities was evaluated during two growing seasons, one relatively dry and the other relatively wet for the region. Although some reduction in biomass production was recorded, grain yields were unaffected by early defoliation.

It is concluded that grazing of winter grain crops, early in the growing season, before booting, has a negligible effect on grain yields, because of the overriding effect of climatic and soil conditions during the post-anthesis growth stage. These conditions rarely allow for the attainment of potential grain yields in the northern Negev region with a mean annual rainfall of 250 mm.

Zaban, H., 1981[4,*]. A study to determine the optimal rainfed land-use systems in a semi-arid region of Israel. Ph.D. Thesis, University of Reading, England.

Several land-use systems are practiced under rainfed conditions in the semi-arid region of Israel and others might be introduced. The major possibilities are wheat production in different cropping systems, sheep production on natural and on improved pasture with several feeding strategies, and an integration of wheat and sheep production. This study describes these various forms of land-use quantitatively, in order to compare them on a common basis and according to common criteria, with the goal of determining optimal systems for various conditions.

Dependence on a variable rainfall plays an important role for the inhabitants of the region. Inducing the inhabitants of the semi-arid region to pass from a survival ecology to a production ecology requires investment and inputs. Farmers are naturally reluctant to take risks, especially in marginal agricultural areas. The farmer must choose between reducing his costs to a minimum with accompanying minimal risks, and risking more by investing in inputs and possibly producing more.

One conclusion of this study is that a fixed management strategy is more advantageous than a variable or flexible strategy. Tillage, fertilization and planting dates for wheat, and the mating and feeding regimes for sheep, ought to be pre-planned and constant from year to year, despite variability in rainfall. This consistency tends to increase production and profits while reducing risk.

Correlation models and detailed simulation models were built for this study using data from commercial farms and research fields. Results from these models suggest that within the semi-arid regions, appropriate land-use strategies vary not only according to mean annual rainfall but also to personal and political objectives and criteria.

The land-use systems giving the highest profits are: continuous wheat in the 350 mm rainfall region, wheat-fallow for 250 and 200 mm, and integrated sheep and wheat in the 150 mm region. The most stable system in all regions is grazing on non-fertilized pasture with supplementary feeding. To meet the target of a population increase in the semi-arid region, the integrated sheep and wheat system and the fertilized pasture system are preferable. More intensive systems are suitable for higher rainfall areas and less intensive enterprises for drier conditions.

The most economical use of additional water from local or distant sources was found to be the production of high value products in a small part of the total area while using the remainder of the land for production under rainfed conditions. Government compensation schemes which protect farmers from excessive losses in dry years and thus promote the investment required to realize full biological potential in seasons with high rainfall, appear to be justified only in the medium rainfall area (average 250 mm). In the high rainfall areas (350 mm per annum) such schemes are unnecessary as an incentive because it pays farmers to make the investment anyway, and below 200 mm the return on government funds is nil or even negative.

Zlotkowsky, H., 1978. Effect of grazing on the life clycle of selected annual forage plants. Progress Rep., Botany Department, Hebrew University of Jerusalem, Israel.

The purpose of this study was to quantitatively establish the effect of grazing on seed production of some annual plants dominating pastures in the northern Negev. Effects were studied under conditions of both nitrogen and non-nitrogen fertilizer application.

Measurements made included: the phenological phases (vegetative, flowering, fruit setting and seed dispersal); plants per unit area; mean plant weight per unit area; phenological changes of morphological plant

parameters of *Hordeum leporinum* and *Phalaris minor* (number of tillers, spike or panicle weight, green matter weight, total plant weight, number of spikes, or panicles , number of dispersal units, spike or panicle length, number of seeds per square meter).

Preliminary results indicate that grazing reduced seed production of grass species significantly. In addition, grazing delayed peak seed production by almost 20 days.

ACTUAL AND POTENTIAL PRODUCTION FROM SEMI-ARID GRASSLANDS

PHASE TWO

A proposal for a joint Netherlands-Israeli research project
(Items, that were not eventually approved have been deleted).

SUMMARY

In phase one of this project dynamic simulation models were developed for predicting primary dry-matter production in semi-arid conditions. In related research projects, hydrologic models were developed to simulate runoff from small watersheds and micro-catchments with natural and treated surfaces. These models were based on theoretical and experimental studies and were verified in field conditions. Now that many of the basic processes are understood in quantitative terms it is proposed to apply the models to solve pasture management and stock water problems of agro-pastoral systems in the semi-arid and arid zones. At the same time further experiments will be conducted to develop the models to include secondary production (livestock), crop yields and integrated farming systems.

The proposed second phase of this project will treat the following principal themes:

- Definition and analysis of agro-pastoral systems.
- Simulation of grain yields.
- Stock drinking water and its relation to extensive range management and nomadism.
- Effect of stress on the efficiency of feed intake and energy conversion in grazing animals.
- Plant growth/grazing relationships during the (early) growth period.

It is proposed that the project be conducted jointly by scientists from the Agricultural University, Wageningen, the Hebrew University of Jerusalem and the Agricultural Research Organization, Bet Dagan.

INTRODUCTION

In phase one of this project, total dry matter production from grasslands under semi-arid conditions was studied. Three situations were considered:

i. Moisture and nutrients both readily available for plant growth.
ii. Nutrients readily available but moisture limited due to low and erratic rainfall.
iii. Nutrients (nitrogen) and moisture both limiting plant growth.

For each situation, appropriate dynamic simulation models were developed. In related research projects in Israel hydrologic models were developed to simulate runoff from small watersheds and micro-catchments with natural and treated surfaces. All these models can now be applied, with the necessary input and controls to describe plant growth and water harvesting potentials in other semi-arid regions. Some have already been used to estimate the production potential of different areas in the Sahelian zone.

During phase one basic processes were studied without immediate consideration of specific practical applications. Now that many of these processes have been defined in quantitative terms, emphasis can be placed on application to primary and secondary production problems in specific development regions. The results of phase one show that this is a promising approach and in principle should guide the planning of the next phase which will incude the following aspects:

i. Definition of relevant agro-pastoral systems and analysis of management options with the models already developed.
ii. Specific studies dictated by local ecological conditions in a developing country.
iii. Further scientific development of aspects that were not covered in phase one where the manpower and facilities are available.

BACKGROUND

1. Agro-pastoral systems

The different semi-arid and arid agro-pastoral systems can be grouped into three main categories according to the intensity of production:

i. Extensive nomadism where animals are exported to other systems for marketing or finishing.
ii. Integrated cropping and livestock production under dryland conditions.
iii. Intensive, irrigation agriculture and forage production.

Actual management systems may be composed of combinations of these types, locally or regionally integrated. It is considered that most of the

production potential in arid and semi-arid regions is to be found in the first two system types. However, these are systems for which it is difficult to determine optimum management strategies because of large fluctuations in climatic conditions, great spatial heterogeneity and the resultant relatively large number of management options. Furthermore, it is difficult to conduct extensive field trials under controlled conditions in these situations. This is particularly so in developing countries where research facilities and trained manpower are not easily available. Simulation techniques are probably the only effective way to analyse the productivity and management of such systems. In this manner, results of research in more developed countries can be efficiently and rapidly applied to solve urgent problems in developing regions.

2. Some results obtained in phase one

The following experimental results obtained during phase one are relevant to the planning of phase two.

- On deep soils in the semi-arid Negev, nitrogen and not moisture limited primary production in years when the rainfall exceeded circa 200 mm.
- There was almost no difference between the native annual vegetation and highly bred wheat with regard to efficiency of moisture use for overall dry matter production.
- Where rainfall is less than circa 400 mm, there is no deep drainage below the rooting zone of herbaceous species and as a result nitrates are not leached out of the soil. Nitrogen is also not lost by denitrification because the necessary anaerobic conditions are rare in low-rainfall regions. As a result, nearly all nitrogen applied and incorporated into the soil is eventually utilized and converted into plant protein, some of it in subsequent seasons. Six kilograms of plant protein contain about one kilogram of nitrogen.

Even though there were no really dry years during phase one, these results suggest an intensive management scheme that should materially increase the production in these regions both from pasture as well as from crops.

3. Water and nomadic pasture utilization

Large areas of the semi-arid and arid zone carry nomadic and semi-nomadic communities. Maintaining these systems in a developing world necessitates supplying the nomads with an effective means of stabilizing food production on a high level compatible with careful and sound use of the primary resources. This requires the development of systems based on the integrated use of water, pasture and livestock management. In the nomadic situation, often it is lack of drinking water that limits the

utilization of available feed far from the permanent watering points on the one hand and causes extreme over-use and decrease of pasture production near these points, on the other hand. Because of the expense of water development, especially of deep bore-holes, maximum spacing of watering points is intrinsic to water development planning. A much denser pattern of water supply in which the quantity of water at any place is coupled to the availability of pasture feed could effectively increase production and conserve the range at the same time. Over-use of the pasture would be prevented as long as there is no excess drinking water available for the livestock in relation to available forage. Then the water would be finished before the pasture so that the herds would have to move on before the range is destroyed by overgrazing.

All water development should be related to the current productivity of the range, but a system of relatively closely spaced small cisterns based on the utilization of surface water would have some important advantages. For instance, yearly cistern fill and yearly pasture production depend in different ways on the same rainfall events; also, the low cost of individual cisterns make possible a much more diffuse investment which is necessary for more uniform utilization of the range.

In a related research project conducted concurrently with phase one it was shown that water-harvesting systems from both natural and treated surfaces are feasible low-cost techniques that can be applied in regions with annual rainfall as low as 100 mm.

4. Livestock demography

In the semi-arid situation, suitable livestock control and marketing measures are needed to maintain the viability of the production systems. Economic production depends not on the carrying capacity of the range but on the number of marketable animals in suitable condition that can be marketed from the system each year. This will vary from year to year in accordance with current primary production and the population dynamics of the livestock. Only when the livestock demography is properly understood can primary production, secondary production and management be integrated effectively.

PROPOSED RESEARCH PROGRAMME

The studies detailed in this section are proposed with a view to developing principles that can be applied in the context of relevant farming systems. The model development and experiments are planned as an extension of phase one. In the part of phase two that will be implemented in Israel, problems will be studied that are associated with the

utilization of primary production in the form of grain crops as well as pasture and its conversion into usable secondary production, - meat, milk, hides etc. The project will treat the following principal themes:

- Definition and analysis of important agro-pastoral systems in arid and semi-arid regions.
- Simulation of dryland grain yields under semi-arid conditions.
- Stock drinking water as a means of managing extensive grazing systems.
- The effect of large fluctuations in availability and quality of pasture of the efficiency of feed intake and energy conversion in grazing animals.
- Effect of grazing on plant growth and interference between species particularly at the beginning of the growing season.

1. Modelling and analysis of agro-pastoral systems

a. Definition of farming systems and management options. The components for inclusion in systems which are exclusively pastoral (nomadic and sedentary) as well as systems based on the integration of livestock and cropping will be selected. In addition the management options must be worked out. These will include unconventional measures like adequate nitrogen fertilization on dryland pastures, enhancement of native, annual legumes with phosphorus fertilization, cistern development for improved range utilization etc.

b. Analysis. Simulation models will be used to analyse the performance of the various systems under different management and environmental conditions. Animal demography will be given particular emphasis in the extensive systems; integration of cropping with optimally managed dryland pastures and intensive finishing of market livestock will be studied in the context of the agro-pastoral systems. Aspects of stratified production management where different regions participate in different parts of the production process will also be considered.

The analysis of the systems will be done firstly to determine the effects of management on productivity. The more promising management options will then be analysed economically and suitable models to account for changing prices and other considerations will be formulated.

c. Verification. Because it is difficult to verify management models on full scale real systems, alternative validation schemes must be developed in order to test the models and increase confidence in the simulation analysis.

A small farm scale pilot system including cropping and grazing managed on the basis of production of natural annual grasses with adequate nitrogen nutrition and legumes with adequate phosphorus nutrition. This system would be used to test model predictions on both biological and economic criteria.

The pilot system will be established at Migda where most of the phase one field experiments were conducted.

d. Development of agro-pastoral systems for application on a wide scale in semi-arid regions. This is the major purpose of phase two, as been described above.

2. Simulation of dryland grain yields

In phase one, dry matter production was succesfully simulated for different conditions of moisture and nitrogen availability. Simulation of dry matter conversion to grain yields is an obvious field for further development. A beginning has been made with wheat and it is proposed to develop similar programmes for other grain crops relevant to the semi-arid region.

The crop models will then be used in conjunction with pasture grazing models to analyse optimum management combinations as set out in the previous section. They will also be used to analyse the possible effect of different agro-technical methods on grain yields.

3. Stock drinking water and extensive grazing systems

The leading idea here is that in semi-arid regions there is potentially no shortage of drinking water for livestock because livestock need only 2-3 kg of water for each kilogram of dry plant material matter ingested, whereas for every kilogram of dry matter produced by plants, between 500-1000 kg of water are transpired. Thus harvesting some of the water for stock drinking purposes and storing it efficiently can supply all the animal needs without materially affecting plant production. It has been shown that natural surfaces in small micro-catchments can, under certain soil conditions, yield 20-30% runoff. Treated surfaces give 60-90% runoff. If, in addition, the supply of water can be quantitatively limited to the supply of pasture feed, then a self-regulating system could be developed that would allow for optimal, but not excessive use of the pasture.

Such a system could be based on relatively closely spaced cisterns with an efficient water-collecting apron. The problems to be solved involve techniques for cheap and efficient apron development as well as cistern construction.

In order to propose engineering standards and optimum modules for cistern construction and water collection under different rainfall and physiographic site conditions, the following topics must be investigated:

a. Runoff rainfall relationships for various geomorphological and soil conditions.
b. Optimal spacing and capacity of cisterns.
c. Materials for construction of durable cisterns.

d. Materials and methods for establishment of water harvesting aprons.

In the first part of phase two, existing hydrological models that calculate rainfall-runoff relationships will be used together with the existing plant production models to determine optimum amounts of surface water that need be collected. Some showers are ineffective for plant growth. These should be recognized and defined as they should not fill the cistern either.

In the second part of phase two, techniques will be developed for cistern construction. This will include means for excluding silt accumulation, apron design to exclude ineffective rains, cheap durable materials, practical installation methods, etc.

4. Plant-animal interactions

Plant-animal interactions are most critical when pasture feed is not readily available and the growth rate of the vegetation is less than the potential (or satiation) intake rate of the herd. In most years, this occurs generally at the beginning of the growing season but in drought years it may also occur at other periods during the season. Under these conditions both vegetation and animals are stressed and consequently both primary and secondary production can be considerably reduced. During the early growth period, grazing can also have a decisive effect on the grass/legume relationship in a sward composed of annual species. These various aspects of the plant-animal interaction during the early growth period need to be studied if the grazing system is to be properly simulated. The following subjects are particularly relevant:

a. Feed intake and energy conversion in semi-arid conditions. There is a voluminous literature on feed intake and energy conversion by domestic livestock but most of it refers to intensive, temperate pastures. It has been shown in phase one that some of the established feeding standards do not hold under conditions of stress. A study of the feed intake and energy conversion of livestock grazing pasture that fluctuates between extremes of quantity and quality is necessary to adapt the available knowledge to semi-arid conditions.

Accurate and relatively simple techniques for measuring feed intake of grazing animals for different conditions of pasture availability and quality have been developed in phase one. These are also suited to energy balance studies of animals grazing pastures during the early growing period. This information will be incorporated in the proposed grazing models.

b. Legume/grass relationships. Once annual legume plants have become established they generally fix enough nitrogen for their needs. However, during the early growth period they have to compete with the annual grasses

for available soil nitrogen. Their ability to survive this stage will be improved by grazing if grasses are grazed selectively, as they often are. Grazing management could then supplement phosphorus fertilization to increase the amount of legumes in the sward. This aspect of legume/grass relationships can be studied in field conditions in Israel. Some laboratory work on this subject has already begun in Wageningen. Adapting legumes to local ecological conditions will be an important aspect of the project that will be conducted in a developing country in the Sahelian zone.

c. The effect of defoliation on the dynamics of tiller formation and other morphogenetic processes of annual species could be important in determining pasture growth especially when livestock selectively graze leaves and not stems. Some attention should be paid to this aspect of animal-plant relationships when formulating the grazing model.

5. Finally, some of the experiments established during phase one will be maintained for an additional period. The purpose is mainly to verify the models for the inevitable drought years that by chance did not occur during phase one.

MINISTRY OF FOREIGN AFFAIRS

PLEIN 23 · THE HAGUE · TEL. 614941

Governing Council
Hebrew University of Jerusalem

International Technical Assistance Department') Date: November 10, 1977

Subject: Research project "Actual and potential production from semi-arid grasslands" phase II (L I iia) Ref.: JR-269494

Dear Sirs,

1. I agree to the implementation, as part of the programme of cooperation between Israel and the Netherlands for the benefit of developing countries, of the research project "Actual and potential production from semi-arid grasslands, phase II" outlined in the enclosed project description and the annex of 27 June 1976, subject to the following.

2. Item 3, "small mammal grazing system", of your proposed study IV, "plant-animal relationships", is cancelled: the total budget for this study is thus reduced to 364,700 guilders and the Dutch share therein to 217,000 guilders.

3. Study V is cancelled. The planned Dutch contribution of 159,000 guilders will be set aside for a supplementary study, should this prove necessary. I shall decide on the disbursement of the sum after further consultation with you.

4. The coordination of this project with similar projects in Mali and Peru is the responsibility of Professor C.T. de Wit of the Centre for Agrobiological Research in Wageningen. The coordination will be organised as described in this letter and enclosure. The enclosure also includes a budget replacing budget VII in the annex of June 1976.

5. The total Dutch contribution will amount to not more than 1,496,500 guilders.

6. The project will last for three years, beginning 1 October 1977.

7. The studies will be carried out, under the supervision of the Dutch coordinator, by your university. Responsibility for parts of the research may be delegated to the Agricultural Research

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Organization, Volcani Center, in Israel, on the basis of a subcontract to be concluded between you and the Organization; you should inform me as soon as possible thereafter of the nature and extent of any such delegation of responsibility.

8. You are to submit to me for approval a detailed budget for each project year (1 October to 30 September). The draft budget must be sent two months before the start of the project year to which it relates.

9. Payments will be made as follows:
(a) Every three months a declaration is to be submitted of the expenditure actually incurred. Payment will be made after the declaration has been approved.
(b) After I have approved each annual budget (see 8), an initial payment will be made amounting to 30% of the Dutch contribution fro the year in question. This payment will be deducted from the payment made in connection with the last declaration(s) for the same year.
(c) Within a month of the final report (see 13) and final declaration relating to the present phase of the project being approved, the total declared expenditure, less payments made in connection with the three-monthly declarations and any part of any advance payment not yet deducted from such payments, will be transferred to you, up to the maximum referred to under 5.

10. All expenses incurred in connection with inter-project coordination (see 4) will be met out of the total Dutch contribution (see 5): I shall make the payments direct to the body responsible for coordination.

11. I am prepared to meet, up to a maximum of 150,000 guilders, /= actual expenses incurred by you in preparing for the first year of the project.

12. You must obtain the written agreement of the Dutch inter-project coordinator before entering into any commitments which are to be financed from the Dutch contribution and which amount to more than 10,000 guilders.

13. Every six months you will prepare a report in English on the progress of the project, and send copies to the inter-project coordinator, to the Israeli Ministry of Foreign Affairs and to me. When the present phase of the project has been completed, a draft final report is to be sent to me for approval: you will then be responsible for producing 25 copies of the report in English.

14. You will cooperate fully in the preparation by the inter-project coordinator of brief notes (approximately two pages) on the project: these notes, to be prepared each year in December, will be included in an annual publication of a general nature on the research undertaken as part of the Dutch aid programme.

15. All rights regarding the reports, including the final report, and all other information pertaining to the reports, belong jointly to the Dutch State. If your university plans to use the information for other purposes, the Dutch Government must be given advance notice of this fact and of the nature and extent of the proposed use. The Dutch Government reserves the right of refuse your university permission to use the information in this way.

16. I must reserve the right to withdraw from this arrangement with you at any time if I judge that circumstances justify such withdrawal. Expenses already incurred by you in the implementation of the project would then be met by the Netherlands.

17. This agreement is subject to Dutch law.

If you agree to my proposals, I should be grateful if you would indicate the fact by countersigning this letter and the enclosed duplicate, adding the date, then returning the duplicate to me.

MINISTER FOR DEVELOPMENT COOPERATION
For the Minister
Head of Technical Assistance
Preparation Division

ACTUAL AND POTENTIAL HERBAGE PRODUCTION IN ARID REGIONS

Department of Theoretical Production Ecology
Agricultural University

and

Centre for Agrobiological Research (CABO)

WAGENINGEN, THE NETHERLANDS,
AUGUST 1975.

ACTUAL AND POTENTIAL HERBAGE PRODUCTION IN ARID REGIONS

An annotated bibliography of a joint Dutch-Israeli research project (1972-1975)

Aims of the project

The insight in the processes that govern crop growth has been improved during the last 15 years to such an extent that a reasonable assessment of the production capabilities of arable crops and pastures under varying circumstances may be made. At least under conditions that prevail in the developed countries where large production per unit surface is achieved or at least aimed at (9,10). This knowledge has been applied hardly under more marginal conditions as exist in arid regions with erratic rainfall in the average of 250 (winter rain) to 500 (summer rain) mm per year.

Recognizing the growing problems in these arid regions, where animal husbandry is the main system of production, the Dutch Minister for International Development contacted in 1970 some research workers in the Netherlands and Israel. He requested to adapt existing and to develop new methods of assessment of herbage production in arid regions in dependence of weather, soil conditions and type of plant cover.

The actual plan of work was based on work in progress on the simulation of potential production and transpiration of crop surfaces, of transport processes of water, solutes and heat in the soil (6) and on the nitrogen behaviour in the soil on one hand, and the experience with primary production of natural, annual pastures and their exploitation by sheep in the northern Negev on the other hand (16, 18, 20).

The emphasis on marginal conditions necessitated the development of models to account for the water balance of the soil and to relate plant growth to the uptake of water. The effect of limiting nutrients involved a special study of the soil nitrogen balance in addition to the development of models to quantify the influence of nitrogen supply on growth of annual species.

For the research in the field it was necessary to develop practical,applicable methods for characterization of those physiological plant properties that are of ecological importance (11), methods of growth estimation (7) and determination and methods to determine herbage intake by grazing animals (1).

Although the experimental area was an arid zone with winter rains, the models and techniques had to be applicable to regions with summer rains and also for this reason considerable attention was paid to crop growth in summer, necessarily under (sprinkler) irrigated conditions. As far as possible, it was the aim to restrict the necessary input data on weather, soil and plant species to such an extent that after two years of study in a new region, reasonable estimates could be made of the level and yearly fluctuations of the primary herbage production of dry matter and protein. The emphasis being in primary production, the study of the interface with the animal was restricted to the recycling of nitrogen (4) and the influence of grazing during the growth of the crop on production and water use (7). This restriction in the first phase of the project was considered justified because primary production aspects are often too much neglected.

Results

The so-called "basic crop simulator" for the evaluation of potential production and transpiration was further developed in Wageningen, (9, 10) and in Israel especially evaluated against the growth of Rhodes grass, one of the highest yielding grass species that is available for the arid regions (3). Relatively little adaptation was necessary to simulate the closed crop growth and transpiration. Special emphasis was given to regrowth after cutting at various intervals, the effect of cutting on the dynamics of tiller formation and root growth and decay as a necessary sink for photosynthesis products (3).

The program is at such a stage that it may be used with confidence to predict the yield potential within the range of 300 kg dry matter/ha/day for C_4 grasses in arid regions under optimal conditions. Where irrigation and fertilization is practised, the results may be used as a yardstick for actual achievement and for determination of still existing yield limiting causes. It is not visualized that within the arid regions at large, potential yields are a justified goal but within the whole grazing and marketing system, there may be scope for fattening stations where high yields per unit area are desirable and irrigation and fertilisation is practiced. The program is being extended also to simulate the potential yield of alfalfa.

Besides, the same program forms the basis of determining the water use efficiency of plants in dependency of the weather (7). The results of this model were tested

against data collected in the field for three seasons (7). It appeared that a double sampling technique of visual estimates enables determination of standing crop in a heterogeneous vegetation in a short time with good accuracy (17). The yield under these conditions is not only highly dependent on amount of rainfall, because a varying portion of the water is dissipated through the plant and contributes as such to the production (7).

It has been firmly established in theory and in practice that the potential growth rate of natural grassland species is as high as of cultivated species during periods that water and nutrients happen to be available, so that yield potential as such is no reason to introduce so called improved species (7). And this the more so because some of the natural annual species start to form ripe seeds within a few months after germination which may safe-guard the next year's crop.

Eco-physiological studies on some of the winter annuals showed that, when the conditions happen to be optimal, very little difference exists between species, in terms of productivity as well as water use efficiency (11). However, under stress conditions the species develop different strategies. A general distinction that can be made is between "savers" and "spenders", with respect to a limited amount of available water. Several morphological and physiological properties, which can be determined under controlled conditions may help in classifying the species (11).

It appears that under good nutritional conditions in the Negev, yields of 6000 kg/ha dry matter may be obtained with a rainfall of only 250 mm during the winter season (7).

Simulated results in the Sahelian regions (13) provide a less promising picture because the water use efficiency of plants is much lower in regions with summer rainfall, more water is lost by soil-evaporation and because sandy soils retain less water than the deep lossian soils of the Negev. At least these latter soils retain all the water within a potentially rooting zone of 2 meters, so that there is no deep drainage. Then, the only way for water to dissipate is by evaporation from the top soil and by transpiration. Neutron probe measurements of soil water content throughout the season has shown that water loss occurs at practically the same rate under good and bad nutritional conditions. The production in the latter case may, however, be several times lower because of the bad water use efficiency of starved vegetation (4).

The high storage capacity of the soil makes also that a low germination density does not lead to water loss by drainage but only to water use and growth later in the season. It is speculated that low germination densities on shallow, sandy soils may lead to deep drainage of water, less growth, larger grazing pressure in summer, less seeds for next year and so on to disastrous ends. However, it must be said that the problem of seed dispersal and germination has been elusive up to now.

Especially in years with little rain, several germination flushes occur and a considerable fraction of the water may be lost by evaporation. It appears then that the yield is considerably improved by soil heterogeneity that promotes the occurrence of local run on/run off. Heterogeneity is in general yield improving, although frustrating during experimentation (7, 12).

A good nitrogen status of the soil is most easily obtained by means of nitrogen fertilizer and since anaerobic conditions occur hardly, the non-volatisary nitrate disappears only from the soil through the plant, at least if the soil is deep enough to prevent leaching (4, 7). Practically all the nitrate present in the rooting zone is available for uptake by the plant when there is a demand (8). Nitrate not taken up this year because of lack of water, remains for the next season. A small comfort in situations where nitrogen fertilizers in whatever form are likely to be far too expensive. The natural supply of nitrogen for a grass vegetation is through rain and free living nitrogen fixing bacteria. They seem to contribute together about 12 kg N per ha per year (4). The recycling of N through urine appeared negligible because of volatization and that through the faeces was small because of volatization, irreversible drying and the absence of an active soil fauna.

The irratically occurring legumenous species were rhizobium infested, contained relatively large amounts of N and could comprise up to 50 percent of the plant cover (7). The Australian experience with sown legume grass-mixtures is restricted to semi-arid regions with relatively larger amounts of rainfall. However, the practice penetrates to regions with lower rainfall.

A serious problem is that legumenous species are suffering from competition with grasses, that are competitive because of the better nitrogen status of the soil created by the legumes. Techniques of quantifying competitive interference of naturally occurring

species were successfully applied in the Negev pastures (11), and methods are further developed to evaluate the combining ability of species. Legumes are perhaps the only practical means to improve the nitrogen status of natural pastures in many arid regions and in any program on the improvement of primary production, considerable efforts should be put into this.

Programs for the simulation of the nitrogen balance of the soil, that consider the details of microbiological processes are developed in Wageningen. In Israel methods are developed that are based on a yearly accounting (4).

A combination of this latter model, a model on the uptake and redistribution of nitrogen in annual grass species (15) and the model on water use under limited rainfall, forms the basis for a program of crop growth under conditions where both water and nitrogen may be limited during the season. In this program is also included the calculation of seed yield, rather than of dry matter production as such. This may be of special importance when attention is paid to production of small grains.

Keeping in mind that the main use of these (semi-) arid regions is for animal husbandry, some preliminary work on grazing systems was carried out. In the field of methodology it was established that the tritium dilution technique is a reliable and easy method for intake studies (1, 2).

As a basis for further modelling efforts, a critical survey of existing grassland-grazing models was carried out (14). This showed that still a lot of basic research has to be done to bring calculations of secondary production to the same level of sophistication as those of primary production. Attempts are also being made to describe primary production with simple models (19), which can be included in models where most of the emphasis is on the grazing animal.

Concluding remarks

A most promising way to develop new grazing systems and modify existing ways of life, seems systems analyses followed by model synthesis that covers the whole field of primary production, grazing, animal production, herd management and marketing. Our experience with only a small part of the problem is that

only thorough attempts in which scientific analyses and field experimentation are closely linked may lead to results which are worth some trust (5) and that quick results, however attractive on first sight, may be very costly in the long run.

Participants

The following workers have been cooperating in the research program:

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* These research workers were on a full or partial grant of the D.T.H. (International Technical Assistance Department), The Hague.

1. Benjamin, R.W., A.A. Degen, A. Brieghet and H. Tahhan, 1973. The determination of feed intake under grazing conditions from the water turnover of sheep. Proc. Symposium on Water-Animal Relations. Kimberley, Idaho, ed. H.F. Mayland. p. 83-94.

An experiment to test the accuracy of determining the dry matter intake of sheep from their water turnover is described. Water turnover is measured through the tritium (TOH) dilution technique, by taking daily blood samples, after injection of a known amount of tritiated water. The results are compared with calculations of dry matter intake from estimates of standing crop on grazed and ungrazed plots at the beginning and the end of the grazing period.

2. Benjamin, R.W., A.A. Degen, A. Brieghet, M. Chen and N.H. Tadmor, 1975. Estimation of food intake of sheep, grazing green pasture when no free water is available. J. Agric. Sci. Cambridge (in press).

In this paper another two experiments are described with sheep grazing young barley. Daily food intake is determined from the rate of water turnover, using tritiated water. The sheep used were yearling ewes of both German Mutton Merino and fat-tailed Awassi. The calculated food intake is compared with results obtained through the double-sampling technique. Generally the figures do not deviate more than 10%. It is concluded that measurement of the water turnover is a useful technique for the determination of food intake.

3. Dayan, E., 1975. Measured and simulated potential herbage production of Rhodes grass. Ph.D. thesis Hebrew University, Faculty of Agriculture, Rehovoth, (in prep., end of 1975).

This report gives a full description of the experiments carried out on the "wet side" of the project. This includes both undisturbed growth and response to cutting of Rhodes grass (Chloris gayana).

Experimental results of dry matter production, tiller dynamics and water balance of the canopy are compared with results obtained from simulation models, and show reasonable agreement.

Attention is paid to the dynamics of root growth, while an experimental setup to measure root respiration is described.

4. Harpaz, Y., 1975. Simulation of the nitrogen balance in semi-arid regions. Ph.D. thesis, Hebrew University, Jerusalem (June 1975).

In this publication attention is paid to the role of nitrogen in the arid zone. Processes affecting the nitrogen cycle are described and their relevance under arid conditions is discussed. A simulation model is developed, describing the yearly nitrogen balance of semi-arid pasture. It is shown that for the conditions prevailing in the Northern Negev (deep soils, average annual winter rainfall of 250 mm), dry matter production was limited by nitrogen availability in eight out of thirteen years, the other years being moisture limited.

It is shown that carry-over over inorganic nitrogen from year to year is an important term in the nitrogen balance.

The conclusion is, that a relatively simple model, requiring only a limited number of parameters, can be used to describe the interseasonal nitrogen dynamics, from which a first estimation of dry matter production can be derived.

5. Keulen, H. van, 1974. Evaluation of models. Proc. First Intern. Congress of Ecology, The Hague. Pudoc, Wageningen.

In this paper, some problems encountered in the evaluation phase of modelling are treated. It is emphasized that validation studies are often not carried out properly, while the risk of introducing subjective functions in a model is indicated. Some attention is paid to identification and sensitivity analysis.

6. Keulen, H. van, 1975. The use of simulation models in the study of soil moisture transport processes. In: Computer Simulation of Water Resources Systems. Ed. G.C. Vansteenkiste. North Holland Publishing Company, Amsterdam.

The utility of dynamic simulation models for soil moisture transport processes is discussed. Examples are given of models for infiltration and evaporation, showing that accurate results can be obtained if the hydraulic properties of the soil are known in sufficient detail. For application in the field situation, however, the very small time constants are a problem, and a hierarchical approach is proposed, in which the results of these detailed models are incorporated in lower resolution models.

7. Keulen, H. van, 1975. Simulation of water use and herbage growth in arid regions. Simulation Monographs. Pudoc, Wageningen.

This publication gives a description of scope and objectives of the project. It reports on the experiments on dry matter production and water use, carried out during three growing seasons. A simulation model is described, calculating dry matter production under moisture limiting conditions. Where simplifications have been introduced, their basis is given, and detailed models were developed or described, particularly for direct soil surface evaporation and for the calculation of the transpiration coefficient. Some examples of application of the model are given.

8. Keulen, H. van, N.G. Seligman and J. Goudriaan, 1975. Availability of anions in the growth medium to roots of an actively growing plant. Neth. J. agric. Sci. (in press).

A theoretical analysis is given of transport of anions to roots with special reference to NO_3^-. It is shown that with a normal root density practically the whole anion store is available to the plant within a few days. Transport by diffusion only can explain most of the depletion, but mass flow (i.e. transpiration) will enhance the process. Mass flow will especially be important in soils with a high dispersion coefficient (i.e. löss), while the effect is smaller with lower dispersion coefficients (clay, sand).

Finally a formula is proposed to determine whether a given root density is adequate to meet the plants demand for nitrogen and water by diffusion only.

9. Keulen, H. van and W. Louwerse, 1975. Simulation models for plant production. Proc. WMO Symp. "On agrometeorology of the wheat crop", Braunschweig, 1973 (in press).

This paper contains a short description of the simulation model BACROS (De Wit et al., 1975). A comparison is given of calculated and measured rates of photosynthesis, respiration and transpiration of a wheat crop. The measurements were carried out on crop enclosures in the field, using a mobile laboratory.

It is shown that deviations between calculated and measured rates of photosynthesis occur, when

plants are subjected to different temperatures. This is apparently a result of a different temperature response of plants grown in the field, as compared to those grown under controlled conditions. It may therefore be necessary to determine certain plant parameters directly in the field.

10. Keulen, H. van, W. Louwerse, L. Sibma and Th. Alberda, 1975. Crop simulation and experimental evaluation - a case study. In: Photosynthesis and productivity in different environments. Ed. P.J. Cooper. Cambridge University Press.

A survey is given of comparisons of actual and calculated production of a grass sward (Lolium perenne) grown with optimum supply of water and nutrients, and the measured and simulated rates of photosynthesis of this sward. The paper contains a brief description of the principles of the simulation model. Grass swards of different age are measured throughout the growing season. It is shown that the decrease in the rate of dry matter production, both with age and with the proceeding of the growing season, must be mainly attributed to worsening of the photosynthetic capacity of the individual leaves. Some other possibilities have been explored like leaf angle distribution and different respiration rate, which did not account for the observed differences. It is concluded, that the combination of simulation and experimentation leads to improvement of the model and at the same time hints to relevant experiments in order to increase our knowledge about the system.

11. Lof, H., 1975. Water use efficiency and competition of arid zone annuals with special reference to the grasses Phalaris minor Retz and Hordeum murinum. Reports Agricultural University, Wageningen (Mededelingen LH, in press).

This report deals with eco-physiological studies on some of the winter annuals, predominant in the Migda vegetation. In an attempt to provide a quantitative basis for ecological phenomena, special attention is paid to differences in photosynthetic performance, transpiration and competitive behaviour, both under optimum conditions and under conditions of moisture and/or nutrient deficiency. Experiments

were carried out, both under controlled conditions (photosynthesis room and greenhouse) and under field conditions.

It is concluded that differences between plant species do exist, showing up under sub-optimum conditions, especially a distinction is made between "savers" and "spenders", with respect to the available moisture. These differences do not lead to the extinction of the "savers", as other characteristics (early development, shoot/root ratio) are more favorable for the "savers".

It is possible to determine the main characteristics for such a classification under controlled conditions. However, no clue seems as yet available to predict the actual botanical composition of the native vegetation.

12. Noy-Meir, I., 1975. Spatial effects in modelling of arid ecosystems. In: Structure, functioning and management of arid land ecosystems. Ed. R. Perry (in press).

This paper discusses the effects of spatial heterogeneity on the behaviour of arid ecosystems. Attention is paid to horizontal redistribution of water, resulting from local differences in hydraulic properties or exposition of the soil, redistribution of nutrients either with the moisture or through animal activities (ants, rodants), and their influence on productivity. The effect of nomadic migration on the interactions between plants and animals is discussed.

The conclusion is that in ecosystems modelling the effects of spatial heterogeneity must be taken into account, if such models are to be applied to practical problems.

13. Penning de Vries, F.W.T. and H.D.J. van Heemst, 1975. Potential primary production of unirrigated land in the Sahel. ILCA seminar on evaluation and mapping of African rangelands. Bamako, 3-8 March, 1975.

In this study primary production under rainfed conditions is calculated, using the simulation model ARID CROP for a number of combinations of wheather and soil types prevailing in the Sahelian zone. It is shown, that under optimum nutrient conditions plant production ranges from 0-4000 kg above ground dry matter

per hectare per year with 270 mm of rain and from 5000-9000 kg ha^{-1} year^{-1} with 540 mm rain for various soil types.

It may be concluded that preliminary calculations of productivity in hitherto unexplored regions can be made with relatively little effort in data collecting.

14. Seligman, N.G., 1975. A critical appraisal of some grassland models. In: Critical evaluation of systems analysis in ecosystems research and management. Simulation Monographs. Pudoc, Wageningen.

This is a review of about a dozen crop, grassland and ecosystem models, representing different levels of complexity and various approaches to the analysis of grassland systems. Some of the models are treated in detail, while others are only briefly discussed.

It does not pretend to be a complete survey of existing ecosystem models, but gives a clear picture of the state of the art at this moment.

It concludes that up till now grassland models are at best confirming what is already known, but that further development seems possible, so as to lead to reliable extrapolators for management problems.

15. Seligman, N.G., H. van Keulen and J. Goudriaan, 1975. An elementary model of nitrogen uptake and redistribution by annual plant species. Oecologia (in press).

A descriptive model is presented, that calculates nitrogen uptake from the soil and the response to nitrogen of a growing annual canopy. The model accounts for most phenomena observed in the field, although it is not based on a detailed description of biochemical processes. It simulates the rate of vegetative growth, rate of seed fill, death rate of vegetative tissue and changes in nitrogen content of vegetative and reproductive organs as influenced by nitrogen availability. The nitrogen balance of the soil is not included, but nitrates are assumed to be available from fertilization only. The model is intended for use in conjunction with the model ARID CROP.

16. Tadmor, N.H. and I. Noy Meir, 1973. Methodology for the study of productivity in arid ecosystems. Mexican-Israeli Symposium on Arid Zone.

In this paper a discussion of methodology and problems encountered in integrated studies of plant and animal productivity is given, with special reference to arid and semi-arid ecosystems, partly based on experiences in the early stages of the present project.

17. Tadmor, N.H., A. Brieghet, I. Noy Meir, R.W. Benjamin and E. Eyal, 1975: An evaluation of the calibrated weight-estimate method for measuring production in annual vegetation. J. Range Manag. (in press).

A description of the method to measure standing crop in non-homogeneous plant stands, based on calibrated estimates. A statistical treatment is included, with examples taken from two seasons of experimentation in Migda in stands of the native annual vegetation.

18. N.H. Tadmor, E. Eyal and R.W. Benjamin, 1974. Plant and sheep production on semi-arid annual grassland in Israel. J. Range Manag. 27: 427-432.

In this paper the results are summarized of ± 12 years of grazing experiments on the Migda experimental site. Grazing was entirely on unimproved native pasture consisting of herbaceous annuals. Dry matter yields vary from 2-4 ton ha^{-1} $year^{-1}$, which is sufficient to support unsupplemented year-round grazing of 1.0 - 1.7 $sheep\_ha^{-1}$. Annual lamb production was between 30-60 kg ha^{-1}.

19. Wallach, D., 1975. The effect of environmental factors on the growth of a natural pasture (in prep.)

In this paper the effects of environmental factors on the growth of a natural pasture are studied by assuming a logistic growth curve, in which the relative growth rate is a function of (measured) soil moisture and temperature. The parameters are optimized, to achieve a best fit with the measured production, using a non-linear least squares technique. The data used are those of three seasons of measurements at the Migda site. It is shown that soil moisture is the most important variable, while temperature is only of marginal importance.

However, even with the relative growth rate as a function of both soil moisture and temperature, the fit to the data is not fully satisfactory.

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