Journal of Agriculture in the Tropics and Subtropics
Volume 102, May 2001, pp. 19 - 32

Optimization of forage area utilization in dairy cattle kept in the subtropical zone

Andrzej Zurek*

Abstract

Model studies on optimal utilizaton of forage area for cow milk production in the subtropical zone were carried out. The linear programming method was used for calculations and initial programmes (models) on the basis of materials obtained in Israel and Turkey were made. In some cases data from professional literature were also applied. In 30 best solutions the annual milk production from 1 ha of forage area exceeded 16 000 kg (maximum value 16 137 kg), at the daily milk yield per cow ranging from 24 to 33 kg and animal number ranging from 1.6-2.2 structural cows per ha. The increase in daily milk yield of cows and in milk production per unit of forage area was accompanied by changes in structure of forage crops. In solutions with the lowest milk production most of the area was occupied by plants cultivated for green forage, hay and silage (Alexandrinum clover, maize for silage, Sudan grass). In solutions with higher levels of milk production their area decreased in favour of barley and maize grown for grain and straw, cotton for seeds used as feed, and lucerne. The elaborated models can be used, after slight modifications, for optimization of forage area utilization in other climatic zones, including the temperate zone.

Key words: subtropical zone, linear programming, optimization, forage area, milk production

1 Introduction

The production of cattle and other ruminants is based mostly on farm-grown feeds. In the situation of limited area of agricultural land in the world, especially in the subtropics, the competition grows between plants designed for human nutrition and plants serving as animal feed. Therefore, the optimal utilization of land designed for fodder plants, ensuring the highest possible animal production per unit of forage area, has become more and more essential.

Among ruminants, the cattle, especially those utilized for milk, are of vital importance in many countries in the tropics and subtropics where milk and its products are the main source of animal protein for the local population. Yet, the annual per capita milk production in Africa (22 kg) and in Asia (24 kg) is many times lower than in Europe (296 kg) (FAO Production Yearbook, 1997).

* University of Agriculture in Krakow, Department of World Agriculture, Krakow, Poland

The climatic conditions of the subtropical zone allow the year-round production of animal forage, provided that water supply is sufficient. In such optimal conditions, the animal production achieved per unit of forage area could theoretically exceed that of the temperate zone.

In the subtropics, on irrigated land, some fodder crops are grown in summer and others in winter season. They often supplement each other and can be preserved as silage or hay to meet the demands of animals throughout the year and to secure the proper balancing of feeding rations. There are many evidences that, in spite of often difficult climatic conditions in the subtropical zone, especially in summer months, it is possible to achieve there high levels of milk productivity in cattle. In Israel, for example, the average milk yield of cows increased from 3690 kg in 1934 to 9748 kg in 1994 (Israel's Dairy Board, 1995). Such high yields have resulted from proper care, management and nutrition. At the same time, similar cattle kept in neighbouring countries show much lower level of milk productivity.

The goal of investigations carried out consisted in model studies on optimum utilization of forage area for milk production at the conditions of subtropical climate. In other words, the capacity of irrigated plot of land (10 ha) situated in the subtropical zone for the highest possible milk production in a given period of time (one year) has been studied. For the construction and computation of models, the linear programming method has been applied.

Model studies based on the linear programming method have often been used to solve various problems of animal production (Ewing *et al.*, 1986; Paris, 1991; Schiere *et al.*, 1999; Zurek, 1999). After Ewing *et al.* (1986), model solutions can be even better than those achieved at the production level, but should be confronted with practice to ensure their application. Nietupski and Czerwinski (1975) say that each model is a simplification of existing reality. Models too complicated require more time for their elaboration and, consequently, obtained solutions are no more actual because in the meantime the data were changed. On the other hand, mathematical models allow to modify the values of investigated factors and to obtain many variants of optimal solutions. It increases their applicability in practice.

2 Materials and methodology

Basic data for the construction of models were derived mostly from Israel and Turkey, in particular from the central plain of Israel adjoining the Mediterranean coast, and from the Adana lowland in south-east Turkey, also lying close to the sea. In both regions, a typical sub-tropical climate of the Mediterranean type prevails. It is characterized by long, hot and dry summers, and humid, mild winters. As it appears from the FAO Agroclimatological Data (1987), in both regions air temperatures, monthly or annual, are similar or almost identical. It is shown in the table 1.

It can be said that in Adana summer temperatures are somewhat higher and winter temperatures lower than those registered in Bet Dagan. 80% of annual precipitation in Adana (639 mm) and 96% in Bet Dagan (535 mm) occur during winter period and irrigation is necessary to secure the continuity of crop production throughout the year.

Table 1: Mean, maximum and minimum air temperatures and precipitation registered in Bet Dagan (Israel) and Adana (Turkey)

	Temperature (°C)									Precipitation (mm)
	January			July			Year			Year
	mean	max	min	mean	max	min	mean	max	min	
Bet Dagan (Israel)	12.3	17.9	6.6	24.9	30.6	19.3	19.0	25.2	12.9	535
Adana (Turkey)	9.2	14.2	4.6	27.6	33.9	21.9	18.7	25.2	13.1	639

Source: FAO Agroclimatological Data (1987).

In both areas an intensive crop production prevails; apart from vast citrus fruit plantations also field crops: grain (maize, wheat, barley), peanuts and cotton are grown, accompanied by forage plants, such as alfalfa, Alexandrinum clover, Sudan grass and sorghum. Practically all voluminous fodder for animals comes from field production and permanent pastures do not exist. After Dovrat and Arnon (1972), grazing of animals in the subtropics causes up to 25% losses in pasture overgrowth which is in disaccord with land deficit and high costs of irrigation.

In Israel and urbanized areas of Turkey, like Adana region, milk cattle belong mostly to Holstein-Friesian breed. In Israel they are the sole milk producer and show record yields of milk, exceeding 9000 kg per cow annually (Israel's Dairy Board, 1995). Milk yields recorded in Turkey are much lower, usually do not exceed 6000 kg per cow. The reason is unsufficient feeding and care, mostly during summer months when high air temperatures require special measures (showers, adequate feeding rations) to maintain the milk productivity of cows.

Basic data for construction of initial programmes (models) were derived from a number of dairy cattle farms in Israel and Turkey. Besides, other data and informations obtained from literature were applied, as, for example, nutrient requirements for dairy cattle and nutritional value of particular feeds, taken generally from NRC tables (1988) and, in some cases, accepted after Gohl (1975), Jarridge (1989) and Legel (1981). The reason was lack of reliable feed analyses, especially in the case of Turkey.

In initial programmes (models), the criterion of optimization has been the maximization of annual milk production from 10 hectares of irrigated area cultivated the whole year round, without any purchase of feed from outside. It has been accepted that the basic unit of cattle herd is 1 dairy cow weighing 600 kg and producing milk with the normalized butterfat content of 4% during the 300-day lactation. In initial programmes the dairy cattle stock have been presented in structural cows (cattle units), expressing in singular form the internal structure of the herd of cattle. One structural cow includes an adult female together with her offspring and simple reproduction in the period of one year.

For example, at 5-year utilization and 80% calvings of cows, 1 structural cow would consist of:

1 adult dairy cow
+ 0.8 calf (0.4 female and 0.4 male) up to 0.5 year,
+ 0.4 young heifer 0.5-1.5 year,
+ 0.2 pregnant heifer 1.5-2.5 year for own reproduction,
+ 0.2 pregnant heifer 1.5-2 year for sale.

In the above case, male calves are sold after attaining the age of 0.5 year and old culled cows leave the herd as soon as they are replaced by freshly calved heifers, so these two categories of animals are not included into structural cow. All cows are artificially inseminated.

When it concerns the calculation of annual food requirement, though, the above coefficients would change accordingly to the length of feeding period of a given category of animals. It will look as follows:

1 adult dairy cow
+ 0.4 calf (0.2 male and 0.2 female) up to 0.5 year,
+ 0.4 young heifer 0.5-1.5 year,
+ 0.2 pregnant heifer 1.5-2.5 year for own reproduction,
+ 0.1 pregnant heifer 1.5-2 year for sale.

In the present model studies on optimum utilization of forage area in dairy cattle kept in the subtropical zone, the following levels of production factors have been investigated:

- 3, 4, 5 and 6 years of cow utilization in herd, at the lactation length of 300 days and intercalving period lasting 1 year,
- 70, 80 and 90 weaned calves obtained from 100 yearly (70, 80 and 90 percent of calvings),
- daily milk production per cow starting from 10 kg milk (4% butterfat), with the rate of increase equal to 1 kg or its multiplicity - up to the last attainable optimum solution,
- three levels of yields of forage plants: low, medium and high.

In the year, two main vegetation and feeding seasons, winter season and summer season, each lasting 183 days, have been distinguished. It corresponds with intensive cultivation systems on irrigated land in the Near East and North Africa, in the zone of Mediterranean type of subtropical climate. The winter vegetation season lasts there from the middle of October till mid-April while the summer season respectively from the middle of April till mid-October. Following sets of forage plants have been inserted into initial programmes:

- **winter season:** Alexandrinum clover for green forage and hay, green wheat for silage, barley for grain and straw, lucerne for green forage,
- **summer season:** maize for silage, maize for grain and straw, Sudan grass for green forage and silage, lucerne for green forage and hay, cotton (seeds for forage).

The above mentioned forage plants are widely used in the Mediterranean subtropical zone. The use of cotton seeds for high-productive dairy cows was mentioned by Lubis *et al.* (1990), Harrison *et al.* (1995) and Bitman *et al.* (1996).

The reciprocal exchange of feeds between winter and summer seasons has been introduced into initial programmes in order to meet better the feeding requirements of cattle throughout the year and in this way to improve the efficiency of forage area utilization for milk production. Thus feedstuffs produced in winter can be used also during summer season and those manufactured in summer also during winter season.

Feeding requirements for separate categories of cattle and nutrient composition of feeds were mostly taken from National Research Council tables (1988), and only some figures were derived from Gohl (1975), Legel (1981) and Jarridge (1989). The requirement of following nutrients have been inserted into initial programmes:

dry matter (DM) - in kg,	Calcium (Ca) - in kg,
metabolic energy (ME) - in Mcal,	Phosphorus (P) - in kg,
crude protein (CP) - in kg.	

It was assumed that voluminous fodder should constitute at least 30% of dry matter of feeding rations in dairy cattle (Amir *et al.*, 1985; Amir and Halevi, 1987). At the same time, the excess of dry matter in optimal solutions couldn't be higher than 5% of the whole requirement. It helped to avoid the unnecessary surpluses of nutrients and excessive amounts of separate feeds.

In order to obtain the correct areas of particular forage plants, being in accordance with sequence of plants, adequate balance equations were included into initial programmes. They ensured, for example, that the area of cotton cultivated for seeds was not bigger than the area of her forecrops: green wheat for silage and Alexandrinum clover with the shorter cultivation period, without the last cut designed for hay. In the case of barley and maize cultivated for grain, with their straw utilized as fodder, it was determined that the area cultivated for straw couldn't be bigger than the area cultivated for grain. It allowed to design for fodder the whole yield of straw or its part and increased the elasticity of initial programmes.

It was also determined that lucerne, cultivated the whole year round, gived 75% of the whole yield of green mass in summer season and the remaining 25% in winter. 2/3 of the summer yield was fed to cattle as green forage and 1/3 was dried to hay and designed for the winter season, while the winter yield of lucerne was utilized only as green forage. In the case of Alexandrinum clover, grown in winter season, 2/3 of the whole yield was fed as green forage and 1/3 was dried to hay and designed exclusively for the summer season.

The reciprocal exchange of feeds between winter and summer seasons was accomplished by introducing into initial programmes double variables (columns) for a given plant, each indicating the same amounts of separate nutrients obtained from one hectare of a plant, but designed to be fed to cattle either in winter or in summer season.

Description of initial programmes

The initial programmes (models) were elaborated separately for the low, medium and high level of yields of particular forage crops. Optimum solutions were obtained with help of the LP88 computer programme. The matrix of each programme contained 29 production variables and 29 balance equations. The criterion of optimization wass the maximization of milk production from 10 ha of irrigated forage area cultivated the whole year round. The area of 10 ha was chosen because of simplicity of further recount and having in mind the capacity of the LP88 computer programme. The only difference between three initial programmes consisted in values of matrix coefficients, indicating amounts of separate nutrients achieved from 1 ha of particular forage plants at low, medium and high level of yields. The initial programme for the low level of yields of forage plants (concise view) is presented in table 2.

Table 2: Initial programme for the optimization of forage area utilization in dairy cattle kept in the subtropical zone - low level of yields of forage plants (concise view)

Balance equations	Production variables									Right hand side
	X.1	X.2	X.3	X.4	X.5	X.6...	X.10	X.11...	X.28	X.29	
Y.1							1	1			= 10
Y.2	-7973	-226.9	-287.3	170.2	277.4	341.5	11286		6876		>=0
Y.3	-387.9	-16.47	-15.56	9.7	15.6	19.19	648		450		>=0
Y.4	-14.52	-0.587	-0.485	0.205	0.333	0.41	14.6		2.2		>=0
Y.5	-9.65	-0.362	-0.329	0.146	0.238	0.293	14.6		9.7		>=0
Y.6	-3694	-65.88	-119	80.52	129.9	159.2	5400		1800		>=0
Y.7	-3879	-69.17	-125	84.55	136.4	167.2	5400		1800		<=0
Y.8	-1108	-19.76	-35.69	24.16	38.98	47.76	5400				>=0
Y.9									1	1	=10
Y.10	-7973	-226.9	-287.3	170.2	277.4	341.5		11286		6876	>=0
Y.11	-387.9	-16.47	-15.56	9.7	15.6	19.19		648		450	>=0
Y.12	-14.52	-0.587	-0.485	0.205	0.333	0.41		14.6		2.2	>=0
Y.13	-9.65	-0.362	-0.329	0.146	0.238	0.293		14.6		9.7	>=0
Y.14	-3694	-65.88	-119	80.52	129.9	159.2		5400		1800	>=0
Y.15	-3879	-69.17	-125	84.55	136.4	167.2		5400		1800	<=0
Y.16	-1108	-19.76	-35.69	24.16	38.98	47.76		5400			>=
0											
...											...
Y.24							1	1	-1	-1	>=0
Y.25		-1									=0
Y.26			-1								=0
Y.27				-1							=0
Y.28					-1						=0
Y.29						-1					=0
Criterion of optimization:											
	3000	300	0	0	0	0	0	0	0	0	= max.

Where:

Production variables:

X.1 - structural cow (3 years of utilization, 70% calvings, 10 kg of average daily milk yield in 300-day lactation),

X.2 - increase of daily milk yield by 1 kg,

X.3 - increase of calvings by 10 percent,

X.4, X.5, X.6 - increase of utilization length of cow from 3 to 4 years (X.4), from 3 to 5 years (X.5), and from 3 to 6 years (X.6),

X.10 - 1 ha of green wheat for silage cultivated in winter season and designed for winter season,

X.11 - 1 ha of green wheat fcr silage cultivated in winter season and designed for summer season,

X.28 - 1 ha of seed cotton cultivated in summer season and designed for winter season,

X.29 - 1 ha of seed cotton cultivated in summer season and designed for summer season.

Balance equations:

Y.1 - forage area - winter season (equal to 10 ha),

Y.2 - metabolic energy - winter season (Mcal),

Y.3 - crude protein - winter season (kg),

Y.4 - calcium - winter season (kg),

Y.5 - phosphorus - winter season (kg),

Y.6 - dry matter (lower limit) - winter season (kg),

Y.7 - dry matter (upper limit) - winter season (kg),

Y.8 - the equation ensures that at least 30% of requirement of dry matter (in kg) in winter season is covered by voluminous fodder,

Y.9 - forage area in summer season (equal to 10 ha),

Y.10 - metabolic energy - summer season (Mcal),

Y.11 - crude protein - summer season (kg),

Y.12 - calcium - summer season (kg),

Y.13 - phosphorus - summer season (kg),

Y.14 - dry matter (lower limit) - summer season (kg),

Y.15 - dry matter (upper limit) - summer season (kg),

Y.16 - the equation ensures that at least 30% of requirement of dry matter (in kg) in summer season is covered by voluminous fodder,

Y.24 - the equation ensures that the area of seed cotton is not higher than the area of its forecrops,

Y.25 - the equation enables the increase of daily milk yield above 10 kg by 1 kg (300 kg per lactation) or its multiplicity; in the column X.1 adequate values are inserted (1 = 1 kg milk, 2 = 2 kg milk, etc.),

Y.26 - the equation enables the increase of calving percentage, starting from 70%, by 10 percent or its multiplicity; in the column X..2 adequate values are inserted (1 = 10% calvings, 2 = 20% calvings, etc.), Y.27, Y.28 and Y.29 - the equations enable the increase of utilization length of cows from 3 to 4 years (Y.27), from 3 to 5 years (Y.28) and from 3 to 6 years (Y.29), by inserting "1" in the column X.1.

Right hand sides (R1...... R29). For the balance equations Y.1 and Y.9 they are equal to 10 (ha), and for the remaining balance equations they are equal to zero.

Criterion of optimization (C). For the production variable X.1 (structural cow) the coefficient c1 is equal to 3000 (10 kg of milk daily during 300-day lactation) and for X.2 (increase of daily milk yield by 1 kg) the coefficient c2 is equal to 300 (1 kg of milk daily during 300-day lactation). For the remaining production variables (X3 ..., X.29) the coefficients c3 .... c29 are equal to zero.
A given element amn of the matrices of initial programmes, on the crossing of the m row and the n column, illustrates how many units of the production factor Ym is produced, or used, by 1 unit of the activity (production variable) Xn. For example, how many Mcal of metabolizable energy is produced by 1 ha of wheat for silage at a given level of yields, or how many Mcal of metabolizable energy is used by 1 structural cow of a given milk productivity during winter season lasting 183 days.

3 Results and discussion

From 1030 optimal solutions obtained for all possible combinations of investigated factors, 347 solutions for the low level, 342 solutions for the medium level and 341 solutions for the high level of yields of forage plants were received .
For the particular levels of daily milk yield per cow, starting from the initial 10 kg and increasing by 1 kg or its multiplicity up to the level of 36 kg milk daily - the optimal solutions for all possible 36 combinations were achieved. In the interval from 37 kg to 40 kg milk per day, the optimal solutions for only a part of possible combinations were obtained and above the level of 40 kg of daily milk yield per cow no optimal solutions were received. It is presented in the table 3.

Table 3: Numbers of obtained optimal solutions for specified levels of caily milk yield of cows

Daily milk yield of cows (kg)	Numbers of possible combinations	Numbers of obtained optimal solutions
37	36	30
38	36	19
39	36	7
40	36	1

Worst solutions, with the lowest milk production per 10 ha of forage area, were obtained for all combinations of investigated factors at the lowest, initial level of 10 kg of daily milk yield per cow. Best solutions for particular combinations of investigated factors, with the highest milk production, were achieved at the level of 30-34 kg of daily milk yield per cow. The milk production in the best solutions was 35-40% higher than that in the worst solutions.

The increase of milk production from the minimum to the maximum level was accompanied by the growing milk productivity of cows and, at the same time, by the decrease in number of structural cows.

In 30 optimal solutions, obtained at the range of daily milk yield from 24 to 33 kg, the annual milk production from 10 ha of forage area exceeded 160 thousand kg milk (16 000 kg milk from 1 ha), with the number of structural cows ranging from 1.6 to 2.2 per 1 ha. Basic figures for the best and the worst optimal solution are shown in the Table 4.

Table 4: Basic figures for the best and the worst optimal solution

		Milk production (kg)
Worst solution: low yields of forage plants, 10 kg milk per cow daily, 3 years of utilization and 90% calving of cows		76 928
Best solution: high yields of forage plants, 30 kg milk per cow daily, 6 years of utilization and 70% calving of cows		161 369
Difference:	kg	+84 541
	%	+ 110
		Structural cows
Worst solution:		25,609
Best solution:		17,930
Difference:		7,679
	%	-30

On a given level of milk productivity, the increase of utilization length of cows from 3 to 6 years have resulted in higher milk production, especially in worst solutions (up to 4%). It was caused by lower replacement rate in cows, lesser share of calves and heifers in the herd structure and, in consequence, lower feeding requirements of structural cow kept for 6 years; all this allowed to increase the number of structural cows and raise the milk production from 10 ha of forage area.

On the other hand, the increase of calving percentage from 70% to 90%, on a given level of milk productivity of cows, produced a certain drop in milk production, amounting to 7% in worst solutions and about 3% in best solutions. The reason was the higher percent of calves and heifers in the herd structure and eventually the higher feeding requirements of structural cows which brought down their number and decreased the milk production from 10 ha of forage area.

After the maximum level of milk production had been achieved, the further increase of daily milk yield of cows brought the decrease in the number of structural cows and a growing drop in milk production, the biggest in last attainable optimal solutions. It is presented in table 5 for the configuration of factors of the best solution (6-year utilization and 70% calving of cows, high yields of forage plants).

Table 5: Milk production and number of structural cows in the best and the last attainable optimal solution

Daily milk yield of cows	Milk production from 10 ha of forage area (kg)	Number of structural cows
30 kg (best solution)	161 369	17.93
36 kg (last attainable solution)	150 125	13.90
Difference	-11 244	-4.03
%	-7.0	-22.5

In particular optimal solutions, big differences in the structure of forage plants can be seen. In the worst solutions, obtained at the level of 10 kg of daily milk yield of cows, most of forage area in the winter season is occupied in by Alexandrinum clover for green forage and hay and green wheat for silage, and in the summer season all area is occupied by maize for silage and Sudan grass for green forage. At the higher levels of milk production per unit of forage area, the above fodder plants are steadily replaced by barley and maize grown for grain and straw, and by cotton grown for seeds. Other supplementary fodder plants are: green wheat grown in winter season, Sudan grass grown in summer season, and lucerne cultivated the whole year round. The crop structure of the forage area in the worst and the best optimal solution is shown in table 6.

Structural cows obtained in optimal solutions, were then converted into physical animal heads with help of appropriate coefficients. As it came out, considerable differences in numbers and mutual proportions of age categories of cattle between separate optimal solutions have taken place. It can be seen in table 7 on the example of the worst and the best optimal solution.

The above seen differences in quantities of calves and culled cows designed for sale were bigger than it would appear from the number of cows in the worst and the best animal solution. They were caused by the higher calving rate of cows in the worst solution and lesser needs of annual herd replacement in the best solution where cows were utilized for 6 years.

Table 6: Crop structure of the forage area in the worst and the best optimal solution

	Worst solution	Best solution
Milk production (kg)	76 828	161 369
Structural cows	25.609	17.930
Winter season:		
Alexandrinum clover (ha)	7.0879	0.1069
Green wheat for silage (ha)	-	2.9940
Barley for grain and straw (ha)	2.9121	5.2875
Lucerne for green forage (ha)	-	1.6116
Summer season:		
Maize for silage (ha)	8.6080	1.2416
Maize for grain and straw (ha)	-	0.7400
Sudan grass for green forage (ha)	1.3920	3.4129
Lucerne for green forage and hay (ha)	-	1.6115
Cotton for seeds (ha)	-	2.9940

Table 7: Animal numbers in structural cows and physical heads of cattle obtained in the worst and the best optimal solution

	Worst solution	Best solution
Milk production (kg)	76 828	161 369
Structural cows	25.609	17.930
Physical heads:		
Dairy cows	25.609	17.930
Calves up to 0.5 year	23.048	12.551
Heifers 0.5-1.5 year	11.524	6.276
Pregnant heifers 1.5-2.5 year for own reproduction	8.451	3.048
Pregnant heifers 1.5-2 year for sale	3.073	3.228
Weaned male calves 0.5 year for sale	11.524	6.276
Culled cows for sale	8.451	3.048

As it was already mentioned, in 30 optimal solutions the milk production from 1 ha of subtropical irrigated forage area, without any purchase of feed, reached the level of 16 thousand kg per year. It was achieved at the cattle stock number varying from 1.6 to 2.2 structural cows per 1 ha of forage area, that is 1.6 -2.2 dairy cows together with their progeny and annual reproduction. The attained level of milk production was higher than that mentioned by Stobbs and Thompson (1978) for the subtropical zone of Australia, where the milk production of 6000-8000 kg per year was obtained from 1 ha of pasture composed of grasses and legumes. After Payne (1990), it is possible to obtain up to 13600 kg milk per year from 1 ha of very good pasture in the tropical zone. Thurbon et al. (1973) report a record milk production obtained from 1 ha of intensively utilized pastures in the tropical zone of Australia. It amounted to 17400 kg per year in Jersey cows, and even 22400 kg per year in Holstein-Friesian cows, kept on the pasture sown with Pangola grass (Digitaria decumbens). It should be mentioned, however, that the above results were obtained by herds consisting only of milk cows, and not by cows with their progeny and annual reproduction (structural cows) as in the present study.

The mathematical models introduced in the present work can be also used, after slight modifications, for the optimization of forage area utilization in cattle and other ruminants reared in various climatic zones. In models designed for the temperate zone, contrary to the subtropical zone, non reciprocal but one-way transfer of feeds from the summer to the winter season takes place. Into such models (initial programmes), according to specific needs, also additional production variables indicating purchase of feeds can be introduced. They do not belong to the forage area, so adequate balance equations, limiting the amounts of particular purchased feeds, should be included into initial programmes.

4 Conclusions

In the present model studies the usefulness of the linear programming method for the optimization of forage area utilization in dairy cattle kept in the subtropical zone was proved. The criterion of optimization of the initial programmes (models) was the maximization of milk production from 10 of irrigated forage area cultivated the whole year round. The reciprocal exchange of feeds between the winter and the summer season and no purchase of feeds from outside was also introduced into initial programmes. The cattle stock was expressed in structural cows (adult cows with their progeny and annual reproduction), reflecting in singular form the internal structure of the herd.

From 1030 received optimal solutions, in 30 solutions the annual milk production per 1 ha of forage area exceeded 16 thousand kg. They were obtained at average daily milk yield of cows ranging from 24 to 33 kg in 300-day lactation and the number of structural cows per 1 ha ranged from 1.6 to 2.2. In the best solution, received at the level of 30 kg milk per cow daily, the annual milk production was as high as 16 137 kg milk/ha and in the worst solution, received at the milk productivity level of 10 kg per day, the milk production was more than two times lower (7693 kg/ha). At the same time, the number of structural cows per 1 ha of forage area (1.79) in the best solution was 30% lower than in the worst solution (2,56).

The further increase of daily milk yield of cows above the optimal level brought a decrease in number of structural cows and a growing decrease in milk production. Above the productivity level of 36 kg milk per day, the optimal solutions were received for only a part of possible combinations of factors and above 40 kg no optimal solutions were obtained.

Parallelly with the increase of milk production, significant changes in crop structure of the forage area were observed. In solutions with the lowest milk production per unit of forage area, almost all acreage was occupied by voluminous feeds, such as Alexandrinum clover, maize for silage and Sudan grass. Together with growing milk production, more and more forage area was occupied by barley and maize grown for grain and straw, and by cotton grown for seeds. The possibility of reciprocal exchange of feeds between winter and summer season was fully utilized in optimal solutions and contributed to the better balancing of feeding rations and more effective utilization of forage area for milk production.

The elaborated mathematical models, with slight modifications, can be also applied for optimization of forage area utilization in cattle and other ruminants reared in different climatic conditions, including the temperate zone.

5 References

AMIR S., HALEVI A. 1987. Planning the dairy industry according to consumer demand for milk consumption, in relation to the amount of roughage in the diet of the dairy cow. Proceed. of Workshop: Replacement of concentrates by home-grown fodder in the diet of high-producing cows. Agricultural Research Organization, Bet-Dagan.

AMIR S., HALEVI A., BRUCKENTAL I. 1985. Forage: concentrates proportions for dairy cows after calving. Volcani Center, Special Publication no 234, Bet-Dagan.

FAO 1985. Agroclimatological data for Asia. Plant Production and Protection Series, FAO, Rome.

BITMAN J., WOOD D.L., MILLER R.H., TYRRELL H.F., REYNOLDS C.K., BAXTER H.D. 1996. Comparison of milk and blood lipids in Jersey and Holstein cows fed total mixed rations with or without whole cottonseed. J. Dairy Sci., 75: 1595-1602.

DOVRAT A., ARNON J. 1972. Pattern of intensive roughage production from irrigated forage and pasture crops in Israel. Bull. Recher. Agron. Univ. Gembloux, Semaine Etude de Problemes. Mediter.: 13-17.

EWING M.A., MORRISON D.A., KINGWELL R.S., PANNELL D.J. 1986. A mathematical programming model of a crop-livestock farm system. Agricultural Systems, 20, South Perth: 243-268.

FAO 1997. FAO Production Yearbook 1996. Vol. 50, Rome.

GOHL B. 1975. Tropical feeds. FAO Agricultural Studies No 96, Rome.

HARRISON J.H., KINCAID R.L., MCNAMARA J.P., WALTNER S., LONEY K.A., RILEY R.E., CRONRATH J.D. 1995. Effect of the whole cottonseed and calcium salts of long-chain fatty acids on performance of lactating dairy cows. J. Dairy Sci., 78: 181-193.

JARRIGE R. 1989. Ruminant nutrition. Recommended allowances and feed tables. INRA, Paris.

LEGEL S. 1981. Futterwerttabellen tropischer Futtermittel. Karl-Marx Univ., Leipzig. Hochschulstudium Trop. u. subtrop. Landw.

LUBIS D., VAN HORN H.H., HARRIS B., BACHMAN K.C., EMANUELE S.M. 1990. Responses of lactating dairy cows to protected fats or whole cottonseed in low or high forage diets. J. Dairy Sci., 73: 3512-3525.

1988. Nutrient Requirements of Dairy Cattle. 6th Revised Edition. NRC, Washington.

NIETUPSKI T., CZERWIÒSKI S. 1975. Zastosowanie modelu matematycznego w systemie zarzπdzania przedsiÍbiorstwem rolniczym. Zag. Ekon. Rol. 4(130): 111-122.

PARIS Q. 1991. An economic interpretation of linear programming. Chapter 18. Cattle ranch management. Iowa State Univ. Press, Ames.

PAYNE W.J.A. 1990. An introduction to animal husbandry in the tropics. 4th Edition. Longman Scientific & Technical, New York.

SCHIERE J.B., DE WIT J., STEENSTRA F.A., VAN KEULEN H. 1999. Design of farming systems for low input conditions: principles and implications based on scenario studies with feed alocation in livestock production. Neth. J. Agric. Sci., 47: 169-183.

STOBBS T.H., THOMPSON P.A.C. 1978. Milk production from tropical pastures. FAO. Animal Feed and Health Papers, 12, Rome.

THURBON P.N., CHAMBERS G.A., SIBBICK R. 1973. Progress report on milk production from cows grazing irrigated, fertilized Digitaria decumbens. Proceed. 3rd World Congress of Anim. Prod., Melbourne.

ZUREK A. 1999. Optymalizacja wykorzystania powierzchni paszowej w chowie byd_a mlecznego w strefie subtropikalnej. Zeszyty Nauk. AR w Krakowie, rozprawy, 247.