JARQ 59 (1), 79-87 (2025) https://www.jircas.go.jp

Dairy Cattle Feed Design Support Program Linked to Optimal Planting Plan for Self-Supplied Feed

Kazushi NISHIMURA*

Division of Dairy Production Research, Hokkaido Agricultural Research Center, National Agriculture and Food Research Organization, Sapporo, Japan

Abstract

Feed design for dairy cattle involves searching for the cheapest possible combination of feeds while considering the sufficiency and balance of Total Digestible Nutrients (TDN), Crude Protein (CP), Neutral Detergent Fiber (NDF), Ether Extract (EE), Dry Matter Intake (DMI), and fiber sufficiency and balance; however, this is not an easy task for those who are unfamiliar with mathematical programming and other numerical optimization methods. Commercial applications automate calculations but are not inexpensive. In addition, the amount of self-supplied feed was limited by the amount of cultivated land under management. Therefore, feed design, including contracts among dairy farmers, upland farmers, and self-supplied concentrate feed, is inseparable from planning self-supplied feed crops. The National Agriculture and Food Research Organization (NARO) has released free feed design software; however, it does not consider a planting plan for self-supplied feed. Therefore, we developed a feed design support program for dairy cattle that calculates feed design and self-supplied feed planting plans by entering various prerequisites such as herd conditions and cultivated land area under management.

Discipline: Information Technology
Additional key words: Python application

Introduction

Since the COVID-19 pandemic, the economic and international situation has become unstable due to turmoil in the global supply chain, inflation as a side effect of monetary easing, the conflict in Ukraine, and yen depreciation. The environment surrounding dairy farming operations continues to be more difficult than ever. According to the Agricultural Price Survey (MAFF 2023), feed prices rose sharply; the composite index for feed was 145.2 as of July 2023, compared to 100 in 2020. Therefore, the importance of contracts between dairy and upland farmers and the self-supply of concentrate feed to stabilize dairy farm management is increasing in Japan.

For example, a certain amount of technology has accumulated in recent years for rice whole-crop silage (WCS) as a material for contracts between dairy farmers and upland farmers. Collective harvesting and marketing by contractors and production and utilization through relative trade can be expected to have economic benefits (Morioka & Nishimura 2021). As for concentrate feed, the production and distribution of feed rice are progressing, and the production and utilization of ear corn silage (ECS), in which only the ears of corn are harvested and used for silage preparation, can also be observed in some cases (GAFSA 2021). All these are effective means of reducing costs in the current difficult daily farming environment.

One difficulty is that using new feed ingredients involves changes to the existing feed design. Feed design for dairy cattle involves searching for the least expensive feed combination possible while considering Total Digestible Nutrients (TDN), Crude Protein (CP), Neutral Detergent Fiber (NDF), Ether Extract (EE), Dry Matter Intake (DMI), and fiber sufficiency and balance; however, this is not an easy task for those who are unfamiliar with mathematical programming and other numerical optimization methods. Commercial applications automate calculations but are not inexpensive.

In addition, the amount of self-supplied feed is

*Corresponding author: kazushin@affrc.go.jp
Received 26 October 2023; accepted 3 June 2024.

constrained by areas of cultivated land under management. Therefore, feed design, which includes an arable-livestock partnership and self-sufficiency of concentrate feed, is inseparable from the planting plan for self-sufficient feed. The National Agriculture and Food Research Organization (NARO) has released free feed design software; however, it does not consider a planting plan for self-supplied feed (Nishimura 2008). The Japanese Feeding Standard for Dairy Cattle 2017 (NARO 2017) includes a feed diagnostic program, but this program is designed to check whether the input feed design meets nutrient requirements, not the feed design itself. The use of foreign-made feed design software such as AMTS has also been introduced (Suzuki 2020), but this also does not take into account the planning of subsistence feed crops.

In management simulations for dairy farming (Fujita & Kubota 2009, Higuchi 1996, Kubota 2015, Morioka & Nishimura 2021, Senda & Oishi 2010), self-supplied feed planting plans and feed purchases are determined to meet the nutrient requirements of the target herd and to maximize income as a whole. In these studies, the simulated model integrates the process of minimizing costs while meeting nutrient requirements, as modeled in Nishimura (2008), with a self-supplied feed production process that takes into account land and labor constraints. However, a self-supplied feed production process considering labor constraints requires a large amount of detailed data, such as work hours for each operation, and the calculations require the creation of a huge program with huge matrices required for the Simplex method or a huge number of mathematical formulas. It cannot be easily implemented, and considering the recent development of contractors, labor constraints can be omitted.

Therefore, we developed a feed design support program for dairy cattle that simultaneously calculates feed design and self-supplied feed planting plans by entering various prerequisites, such as cattle herd conditions and area of cultivated land under management, assuming the use of contractors for cases where labor constraints can be omitted.

Program Overview

The program automatically calculates the nutrient requirements of the target herd, a least-cost forage planting plan, and feed design based on various assumptions entered by the user (Fig. 1). In step 1, the calculation of nutrient requirements is based on the Japanese Feeding Standard for Dairy Cattle 2017 (NARO 2017), and calculates the DMI, TDN requirement, CP requirement, etc., according to the target daily milk yield and herd conditions. In Step 2, the search for a least-cost forage planting plan and feed design that meets the nutrient requirements is conducted using the nutrient value of the feed to be used, unit price, unit yield, etc., as well as the area of cultivated land under management, competition for cultivated land in subsistence forage production, and the number of harvests (two or three cuts of grass) as constraints.

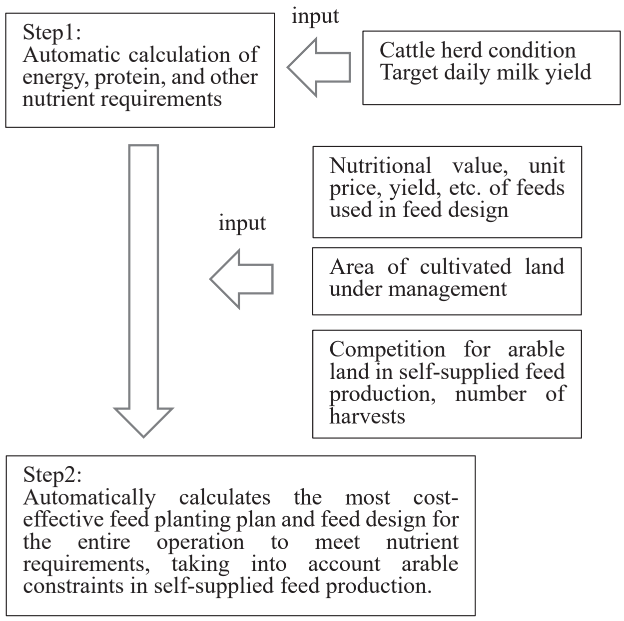


Fig. 1. Process flow in a program

The program is written in Python 3.11 and uses the Pyomo (https://www.pyomo.org/about) library for modeling. The program reads ipopt (https://github.com/coin-or/Ipopt) as a solver to solve linear and nonlinear programming problems and uses pandas, openpyxl, and xlrd to read data from Excel files and format data. Users must build their own Python environments to use this program.

How to enter prerequisites

The prerequisites to be entered and the corresponding sheets in the configuration file (init.xlsx) are listed in Table 1.

1. "cow_condition" sheet

On this sheet, enter target daily milk yield, milk fat percentage, feeding type (separate feeding = 1, TMR (Total Mixed Rations) = 2), average number of days since herd calving, average herd weight, and number of cattle. When designing multiple herds, enter the information for the base herd on the first line and additional information

Table 1. Prerequisites to be entered and the corresponding sheets in “init.xlsx”

Excel Sheet in “init.xlsx”	Setting items
“cow_condition”	Target daily milk yield
	Target milk fat
	Feeding method (Separate or TMR)
	Calving number
	Days after delivery
	weight
	heads
“feed_component”	feed name
	DMI
	TDN (Composition ratio of dry matter)
	CP (Composition ratio of dry matter)
	NDF (Composition ratio of dry matter)
	EE (Composition ratio of dry matter)
	Feed Category (forage or concentrated feed)
	yield (kg/10a)
	cost or price (per kg)
	Upper limit of feeding (kg/day)
	Lower limit of feeding (kg/day)
“grass_competitive”	feed name
	Competitive Flag
“grass_multiple”	feed name
“misc”	Area of cultivated land under management (a)
	Lower limit of NDF in feed desgin (Composition ratio of dry matter)
	Upper limit of EE in feed desgin (Composition ratio of dry matter)
	Upper limit of roughage in feed desgin (Composition ratio of dry matter)
	lower limit of roughage in feed desgin (Composition ratio of dry matter)

for the other herds on the lines below. If the information for multiple herds is entered, the solution to the feed design is the menu for the base herd and the feeding coefficient of the base menu for the other herds, plus the additional feeding of each ration.

2. “feed_component” sheet

On this sheet, enter the feed’s name used in the design, feed composition, unit yield of raw material weight per 10 a (kg/10 a), unit price per kilogram of raw material weight (¥/kg), and upper and lower daily feeding limits (kg per head per day). For feed ingredients, enter the dry matter composition ratio for TDN, CP, NDF, and EE; for roughage, enter 1 for roughage and 0 for concentrate; and for mixed feeds such as TMR, enter the roughage dry matter composition ratio. For self-feeding harvested more than once, the values for each harvesting order were entered. The unit yield of the purchased feed should be set to an appropriate value other than 0 (Setting 0 for the unit yield causes an error).

3. “grass_competitive” sheet

Enter the feed’s name in the first line, 1 in the second and subsequent lines for feeds that conflict with the crop season, and 0 for all other forages. All feed names, including the purchased feed, should be entered on the “feed_composition” sheet. If you have entered the “feed_composition” sheet in order of the number of harvests, enter 1 only for the first harvest. Double cropping, such as a summer or winter crop, enters the first crop in line 2 and the second in line 3. Internally, a constraint was applied to ensure that the total planted area of the feed entered 1 does not exceed the area of the cultivated land under management.

4. “grass_multiple” sheet

If you have entered the self-feeds by cutting order on the “feed_composition” sheet, enter the relationship between the two feeds on the second and subsequent rows. For example, if you entered hay1 and hay2 on the “feed_composition” sheet for grass in double harvesting, enter hay1 and hay2 in the second row of the Roughage1 and Roughage2 columns. Internally, the constraint "hay1 area = hay2 area" is applied.

5. "misc" sheet

Enter the cultivated land area under management (a), lower limit of NDF dry matter composition in the feed design, the upper limit of EE dry matter composition, upper limit of roughage dry matter composition, and the lower limit of roughage dry matter composition.

Methodology

Based on the above inputs, DMI, TDN, and CP requirements are calculated by Step 1 in Figure 1, and optimization calculations are performed in Step 2. In the optimization calculation, the feed design (x_{ij} and α_i) that minimizes the following feed costs is calculated by nonlinear programming.

$$minimize\ 365\sum_{i=0}^{h} H_i\left(\alpha_i\sum_{j=1}^{n} p_j x_{0j} + \sum_{j=1}^{n} p_j x_{ij}\right)$$

$$x_{ij}\ :Daily\ per\ cow\ feeding\ of\ feed\ j\ for\ herd\ i$$
$$\alpha_i: Coefficients\ of\ basic\ design\ (x_{0j})\ for\ herd\ i\ \ (\alpha_0 = 0)$$
$$H_i: Number\ of\ head\ in\ herd\ i$$
$$p_j\ :Feed\ j\ unit\ cost$$

If the target herd is a single herd, the solution obtained is

$$x_{0j}\ :Daily\ per\ cow\ feed\ for\ feed\ j\ in\ herd\ 0.$$

If multiple herds are established, the feed design for herd(i) where i> 0 is estimated using the following formula:

$$\alpha_i x_{0j} + x_{ij}.$$

This is based on the herd(0) feed design and modified for the target herd.

In addition, the following constraints are imposed in minimizing feed costs.

DMI Range: ±5% of DMI calculated in Step 1

$$constraint1\ \ 0.95DMI_i \le \alpha_i\sum_{j=1}^{n} dm_j x_{0j} + \sum_{j=1}^{n} dm_j x_{ij} \le 1.05DMI_i$$

$$DMI_i\ :DMI\ for\ herd(i)\ calculated\ in\ Step\ 1$$
$$dm_j\ :Dry\ matter\ composition\ ratio\ for\ feed_j$$

TDN lower limit: TDN requirement calculated in Step 1

$$constraint2\ \ TDN_i \le \alpha_i\sum_{j=1}^{n} dm_j x_{0j} tdn_j + \sum_{j=1}^{n} dm_j x_{ij} tdn_j$$

$$TDN_i\ :TDN\ requirement\ for\ herd(i)\ calculated\ in\ Step\ 1$$
$$tdn_j\ :Dry\ matter\ composition\ ratio\ for\ tdn\ for\ feed_j$$

CP lower limit: CP requirement calculated in Step 1

$$constraint3\ \ CP_i \le \alpha_i\sum_{j=1}^{n} dm_j x_{0j} cp_j + \sum_{j=1}^{n} dm_j x_{ij} cp_j$$

$$CP_i\ :CP\ requirement\ for\ herd(i)\ calculated\ in\ Step\ 1$$
$$cp_j\ :Dry\ matter\ composition\ ratio\ for\ cp\ for\ feed_j$$

NDF lower limit: user-set value in misc sheet

$$constraint4\ \ NDF\left(\alpha_i\sum_{j=1}^{n} dm_j x_{0j} + \sum_{j=1}^{n} dm_j x_{ij}\right) \le \alpha_i\sum_{j=1}^{n} dm_j x_{0j} ndf_j + \sum_{j=1}^{n} dm_j x_{ij} ndf_j$$

$$NDF\ :lower\ limit\ of\ ndf\ dry\ matter\ composition\ ratio\ setted\ in\ misc\ sheet$$
$$ndf_j\ :Dry\ matter\ composition\ ratio\ for\ ndf\ for\ feed_j$$

EE upper limit: user-set value in misc sheet

$$constraint5\ \ \alpha_i\sum_{j=1}^{n} dm_j x_{0j} ee_j + \sum_{j=1}^{n} dm_j x_{ij} ee_j \le EE\left(\alpha_i\sum_{j=1}^{n} dm_j x_{0j} + \sum_{j=1}^{n} dm_j x_{ij}\right)$$

$$EE\ :upper\ limit\ of\ ee\ dry\ matter\ composition\ ratio\ setted\ in\ misc\ sheet$$
$$ee_j\ :Dry\ matter\ composition\ ratio\ for\ ee\ for\ feed_j$$

Roughage dry matter ratio range: user-set value in misc sheet

$$constraint6\ \ Roughage_{lower\ limit}\left(\alpha_i\sum_{j=1}^{n} dm_j x_{0j} + \sum_{j=1}^{n} dm_j x_{ij}\right) \le \alpha_i\sum_{j=1}^{n} dm_j x_{0j} roughage_j + \sum_{j=1}^{n} dm_j x_{ij} roughage_j \le Roughage_{upper\ limit}\left(\alpha_i\sum_{j=1}^{n} dm_j x_{0j} + \sum_{j=1}^{n} dm_j x_{ij}\right)$$

$Roughage_{lower\ limit}, Roughage_{upper\ limit}$ ：
$range\ of\ roughage\ dry\ matter\ composition\ ratio\ setted\ in\ misc\ sheet$

$roughage_j$ ：
$Dry\ matter\ composition\ ratio\ for\ roughage\ for\ feed_j$

Range of feed: user-set value in feed-component sheet

$$constraint7\ \ X_{lower\ j} \leq \alpha_i x_{0j} + x_{ij} \leq X_{upper\ j}$$

$X_{lower\ j}, X_{upper\ j}$: $range\ of\ x_j\ setted\ in\ feed\ component\ sheet$

Grass multiple harvesting setting: set by the user in grass_multiple sheet

$$constraint8\ \ 365 \sum_{i=0}^{h} H_i \left(\frac{\alpha_i x_{0l}}{yield_l} + \frac{x_{il}}{yield_l} \right)$$

$$= 365 \sum_{i=0}^{h} H_i \left(\frac{\alpha_i x_{0m}}{yield_m} + \frac{x_{im}}{yield_m} \right)$$

l, m ：$Feed\ setted\ in\ grass\ multiple\ sheet$

$yield_l, yield_m$ ：$unit\ yield\ of\ raw\ material\ weight\ setted\ in\ feed\ component\ sheet$

Land competition constraints: set in grass_competitive sheet

$$constraint9\ \ 365 \sum_{i=0}^{h} H_i \left(\alpha_i \sum_{j=1}^{n} \frac{x_{0j}}{yield_j} competition_{rj} + \sum_{j=1}^{n} \frac{x_{ij}}{yield_j} competition_{rj} \right) \leq Land$$

$competition_{rj}$ ：$Value(0\ or\ 1)\ setted\ in\ grass\ competitive\ sheet\ for\ feed\ j\ for\ row\ r$

$Land$ ：$the\ cultivated\ land\ area\ under\ management\ setted\ in\ misc\ sheet$

Program execution and results

The program runs from a command prompt, where Python script can be executed. If the group of program files and init.xlsx are saved in C:¥feed_plan from the command prompt, enter the following command to move from the present directory to the directory of program files: cd C:¥feed_plan. To get the result of a least-cost forage planting plan and feed design, type the following command: python feed_plan.py.

If a solution is found, the prompt outputs the calculation results, as shown in Figure 2. The output includes the herd's feed cost per head per day, the total annual feed cost, the area planted for each feed, the amount of each feed fed per head per day by the herd, and the coefficient (alpha) for the basic menu. In Figure 2, the herd(0) solution is output because the design assumes a single herd. The area of purchased hay is also calculated as output in each feed crop, but this is a specification. Normally, this would be a meaningless number. Still, in the case of rice WCS transactions based on contracts between dairy and upland farmers, the optimal contracted area can be set by setting an appropriate unit yield in the "feed_composition" sheet.

Execution example

1. Initial trial calculation setup (Simulation 1 setup)

(1) "cow_condition" sheet

The target daily milk yield was 30 kg per day per head, the target milk fat was 3.8%, the feeding method was TMR, the calving number was 3, the number of days

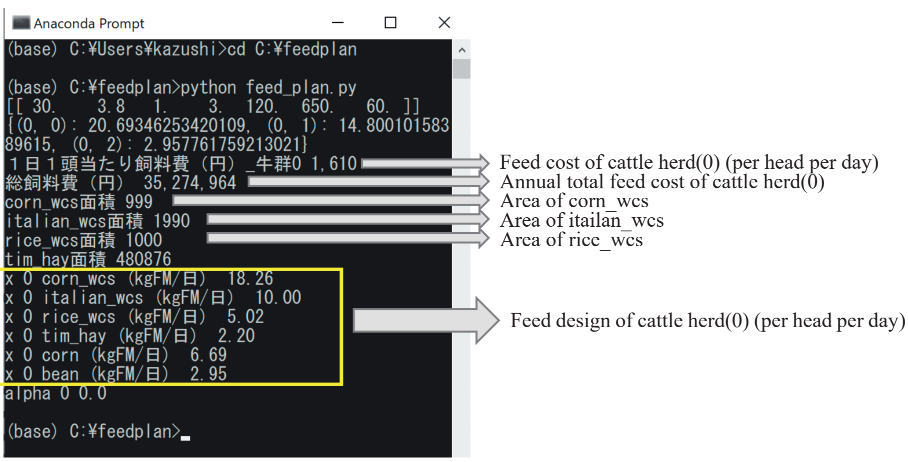


Fig. 2. Program Output

milk	fat	feed_type	calving_number	calving_day	weight	heads
30	3.8	2	3	120	650	100

Fig. 3. “cow_condition” sheet of Simulation 1

feed	dm	tdn	cp	ndf	ee	roughage	yield	cost	max	min
corn_wcs	0.28	0.68	0.09	0.51	0.031	1	5054.31	4.43	25	0
ecs	0.648	0.831	0.081	0.269	0.039	0	1492.53	28	0	0
timo_wcs1	0.368	0.548	0.08	0.679	0.037	1	1894.2	6.31	99	0
timo_wcs2	0.605	0.544	0.101	0.606	0.036	1	406.72	6.31	99	0
og_wcs1	0.247	0.683	0.123	0.537	0.056	1	1560	7.3	0	0
og_wcs2	0.244	0.629	0.166	0.523	0.064	1	975	7.3	0	0
og_wcs3	0.442	0.58	0.167	0.503	0.043	1	315	7.3	0	0
corn	0.855	0.936	0.088	0.125	0.044	0	1	86	99	0
bean	0.882	0.87	0.511	0.155	0.022	0	1	133	99	0

Fig. 4. “feed_component” sheet of Simulation 1

corn_wcs	ecs	timo_wcs1	timo_wcs2	og_wcs1	og_wcs2	og_wcs3	corn	bean
1	1	1	0	1	0	0	0	0

Fig. 5. “grass_competitive” sheet of Simulation 1

since calving was 120 days, and the weight was 650 kg (Fig.3).

(2) “feed_component” sheet

Corn WCS (corn_wcs), ear corn silage (ecs), timothy double harvesting (1st grass: timo_wcs1, 2nd grass: timo_wcs2), orchard grass triple harvesting (1st grass: og_wcs1, 2nd grass: og_wcs2, 3rd grass: og_wcs3), grain corn (corn), and soybean meal (beans) were used (Fig. 4).

For corn WCS, the maximum daily feeding limit was set at 25 kg per head per day because high quality is required for high feeding and is not in many cases. For timothy and concentrates, no special restrictions were considered; therefore, the upper limit (max) was set at 99 kg per head per day.

Because ear corn silage (ecs) and orchard grass (og_wcs1-3) were not included in the feed in the initial estimation, the upper limit of feeding was set at 0.

Unit cost (cost: ¥/kg) and unit yield (yield: kg/10a) were set based on statistics and existing surveys (Aoki et al. 2017, Yajima et al. 2020, Department of Agriculture, Hokkaido Government 2019, NARO 2017, MAFF Agricultural Price Survey https://www.maff.go.jp/j/tokei/kouhyou/noubukka/#m).

(3) “grass_competitive” sheet

Because this is a single-cropping case, there is one row. Set 1 for corn WCS (corn_wcs), ear corn silage (ecs), timothy (first grass of, timo_wcs1), and orchardgrass (first grass of, og_wcs1) in the subsistence feed; this means that internally in the program,

area(corn_wcs) + area(ecs)+area(timo_wcs1) + area(og_wcs1) <= Area of cultivated land under management (Fig. 5).

roughage1	roughage2
timo_wcs1	timo_wcs2
og_wcs1	og_wcs2
og_wcs1	og_wcs3

Fig. 6. “grass_multiple” sheet of Simulation 1

item	value
cultivated area(a)	4000
ndf lower	0.35
ee upper	0.05
roughage upper	0.65
roughage lower	0.5

Fig. 7. “misc” sheet of Simulation 1

(4) “grass_multiple” sheet

Because timothy is double harvested, timo_wcs1 and timo_wcs2 were entered in the second row of the throughage1 and throughage2 columns (Fig. 6). The orchard is triple-harvested, og_wcs1 and og_wcs2 are entered in the third row, and og_wcs1 and og_wcs3 are entered in the fourth row. These are interpreted in the program as follows:

area(timo_wcs1) = area(timo_wcs2)

area(og_wcs1) = area(og_wcs2)

area(og_wcs1) = area(og_wcs3)

(5) “misc” sheet

The lower limit of NDF and upper limit of EE were set to standard values (Fig. 7). The upper and lower limits of roughage were set at 0.5 to 0.65 dry matter ratio, which was slightly higher in roughage.

2. Simulation scenarios (settings for Simulation 2 and beyond)

Based on the setting in Simulation 1, we changed the settings of the other simulations to see the result of these changes as follows.

Simulation 2: Change the upper limit of ecs in the “feed_composition” sheet from 0 kg to 5 kg.

Simulation 3: Change the cultivated land area under management in the “misc” sheet from 4,000 a to 5,000 a.

Simulation 4: Change The upper limit of og_wcs1-3 in the “feed_composition” sheet from 0 kg to 99 kg.

Simulation 5: Change the cultivated land area under management in the “misc” sheet from 5,000 a to 6,000 a.

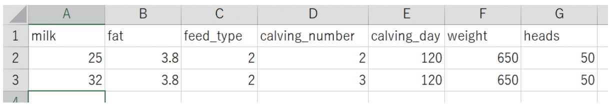
3. Simulation results

The results of simulation scenarios are shown in Table 2. The results of each estimate confirm that DMI, TDN, and CP meet the standards of the Japanese Feeding

Table 2. Simulation results

		Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5
Feed design (kg per head per day)	corn_wcs	25.00	25.00	25.00	25.00	25.00
	ecs	–	0.00	2.90	2.90	5.00
	timo_wcs1	11.39	11.39	12.90	12.90	0.00
	timo_wcs2	2.45	2.45	2.77	2.77	0.00
	og_wcs1	–	–	–	0.00	12.17
	og_wcs2	–	–	–	0.00	7.61
	og_wcs3	–	–	–	0.00	2.46
	corn	5.52	5.52	3.13	3.13	2.01
	bean	3.11	3.11	3.03	3.03	2.28
Feed design composition	DM (kg)	20.14	20.14	20.65	20.65	19.92
	TDN (kg)	14.67	14.67	14.66	14.66	14.66
	CP (kg)	2.93	2.93	2.93	2.93	2.93
	NDF (dry matter %)	41	41	44	44	41
	EE (dry matter %)	3	3	3	3	4
	roughage (dry matter %)	63	63	65	65	65
Area of feed crop (a)	corn_wcs	1,805	1,805	1,805	1,805	1,805
	ecs	–	0	709	709	1,222
	timothy bouble harvest	2,194	2,194	2,485	2,485	0
	orchard grass triple harvest	–	–	–	0	2,847
Feed cost (¥ per head per day)		1,085	1,085	962	962	889
Annual total feed cost (¥)		39,638,060	39,638,060	35,135,789	35,135,789	32,460,036
Reduction in feed costs (%)			0%	11%	11%	18%

Standard for Dairy Cattle 2017 and that NDF%, EE%, and roughage% are within the setting range. Starting from Simulation 1, ecs was made available for incorporation in Simulation 2, but ecs was not selected as the optimal solution; this is because, while ecs is a concentrate feed and has a high TDN, it has a low unit yield and a high cost per dry matter compared to corn_wcs and timo_wcs; hence, the planting and feeding of corn_wcs and timo_wcs were considered a priority. In Simulation 3, the total dry matter composition of corn_wcs and timo_wcs reached 0.65 due to the expansion of the cultivated land under management, so ecs were allocated to the surplus land. In Simulation 4, og_wcs with a higher TDN and CP than timo_wcs were incorporated but not selected in the optimal solution; this may be because og_wcs has a lower unit yield than timo_wcs. In Simulation 5, the increase in the area under management allowed og_wcs to reach the upper limit of 0.65 in terms of roughage dry matter composition, even though it had a low unit yield, and the amount of ecs planted and fed also increased owing to the surplus of arable land under management.



	A	B	C	D	E	F	G
1	milk	fat	feed_type	calving_number	calving_day	weight	heads
2	25	3.8	2	2	120	650	50
3	32	3.8	2	3	120	650	50

Fig. 8. "cow_condition" sheet of Simulation 1 in case of two cattle herd

4. Supplemental simulation (multiple herd setting)

In this program, it was mentioned that multiple herds can be set for the herd condition, which is a prerequisite for the program, and an example of this is shown below. Figure 9 shows the solution search results with two herds set on the "cow_condition" sheet of the previous Simulation 1 (Fig. 8).

The second line of the "cow_condition" sheet is the basic herd and is indexed as 0, and the third line is indexed as the herd (1). The output is the same as before for the basic herd(0), but the amount of feed for herd (1) is lower.

$$\alpha_1 x_{0j} + x_{1j}$$

This indicates that the feed design x_{0j} for herd(0) is considered as one feed and is incorporated into the feed design for herd(1). Although alpha1 has a small value in

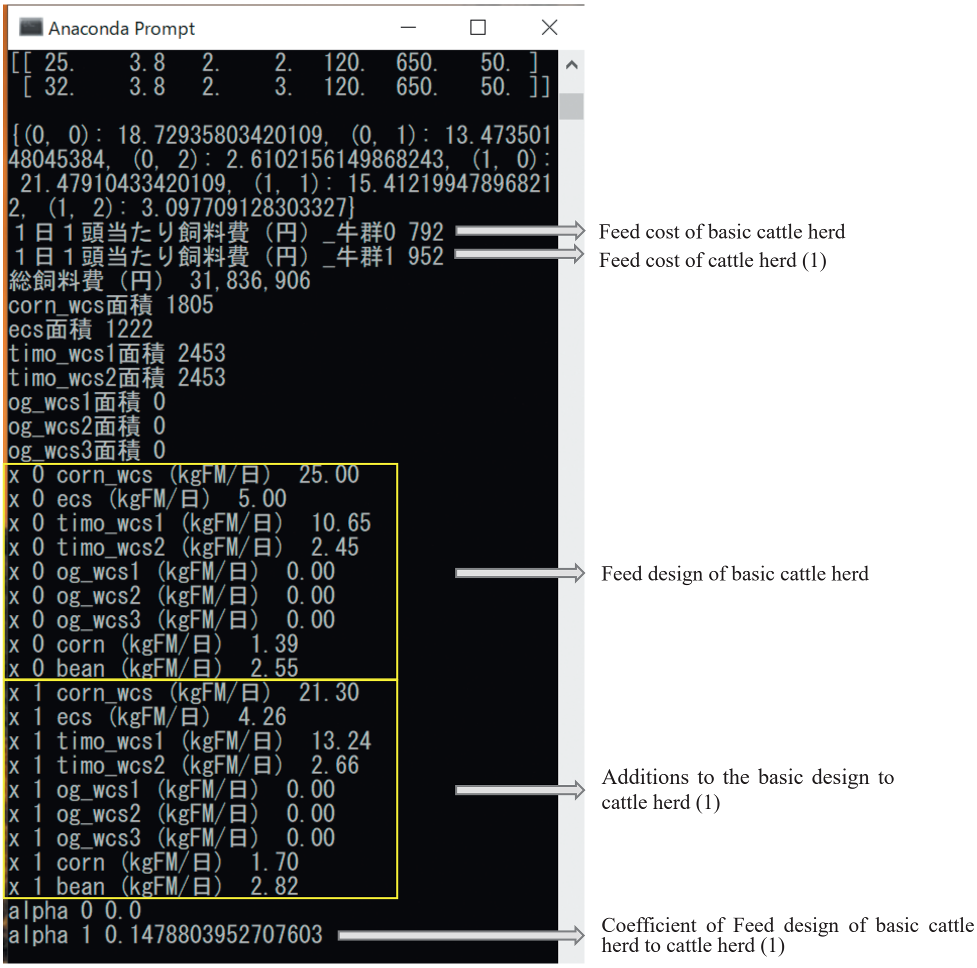


Fig. 9. Output of Simulation 1 in case of two cattle herd

this design, it is conceivable that if alpha1 is of a certain size, the basic menu TMR(x_{0j}) can be fed as is for herd(0), and for herd(1), the basic menu TMR can be fed with the addition and remixing of feeds according to the above formula. Since a large amount of the basic TMR can be prepared at one time, the efficiency of preparation work can be expected to be improved.

Precautions for use

This program does not consider "protein degradability" or "roughage fiber functionality." It is recommended that you refer to Chapter 5, "Feed feeding precautions," of the Japanese Feeding Standard for Dairy Cattle 2017. Also, please remember that the "Feeding Standard" is only an "average model" and does not apply perfectly to all cattle. After designing the menu, adjustments and modifications should be made by observing the conditions of each cow.

How to get it

If you wish to use this service, visit https://www.naro.go.jp/laboratory/harc/inquiry/index.html for more information. This program can be distributed free of charge to government agencies and individual farmers in Japan (other farmers must conclude license agreements).

Acknowledgements

This program is patent pending in Japan in October 2022.

References

Aoki, Y. et al. (2017) *Technical Manual for the Production and Utilization of Earcorn Silage, 2nd ed.* https://www.naro.go.jp/publicity_report/publication/pamphlet/tech-pamph/074438.html [In Japanese].

Department of Agriculture, Hokkaido Government (2019) *Hokkaido Agricultural Production Technology System.* Hokkaido Agricultural Extension Association, Sapporo,

Japan [In Japanese].
Fujita, N. & Kubota, T. (2009) The effect to feed many corn ensilage to cow in dairy farming. *National Agricultural Research Center for Hokkaido Region Farm Management Research*, **100**, pp. 1-12 [In Japanese].
GAFSA (2021) *Collection of case studies on the production and utilization of domestic concentrate feeds*. http://souchi.lin.gr.jp/skill/pdf/concentrated-feed_cases202103.pdf [In Japanese].
Higuchi, A. (1996) Economic Evaluation of Dairy Farming System by Linear Programing Method -Comparison between Free-Stall System and Intensive Grazing System-. *Japanese Journal of Farm Management*, **34**, 104-109 [In Japanese].
Kubota, T. (2015) A model of subsistence dairy farming with farm-based TMR centers. *Miscellaneous publication of the National Agricultural Research Center*, **11**, 20-26 [In Japanese].
Ministry of Agriculture, Forestry and Fisheries (MAFF) (2023) Agricultural Price Survey. https://www.maff.go.jp/j/tokei/kouhyou/noubukka. Accessed on 10 August 2023 [In Japanese].
Morioka, M. & Nishimura, K. (2021) Using Mixed Integer Non-Linear Programming to Develop Dairy Farm Simulation Models for Forage Crop Production Scenario Analysis. *Agricultural Information Research*, **29**, 70-80 [In Japanese with English summary].
NARO (2017) *Japanese Feeding Standard for Dairy Cattle (2017)*. Japan Livestock Industry Association, Tokyo, Japan [In Japanese].
Nishimura, K. (2008) Minimum cost feed design tool for dairy cattle that can be easily used on Excel. https://www.naro.go.jp/project/results/laboratory/karc/2007/konarc07-21.html [In Japanese].
Senda, M. & Oishi, W. (2010) Evaluation and Conditions for Promotion for Rice Whole Crop Silage in Dairy Farm. *Kanto Tokai Journal of Farm Management*, **100**, 115-119 [In Japanese].
Suzuki, Y. (2020) How to use feed design software. *In* Hirokawa, T. (ed) Feed design and feeding basics and practices. Sapporo, Japan, pp. 56-62 [In Japanese].
Yajima, A. et al. (2020) Forage characteristics of grass silage made from orchardgrass and perennial ryegrass mixed meadow, harvested early and at short intervals in Hokkaido, *Nihon Chikusan Gakkaiho*, **91**, 275-280 [In Japanese with English summary].