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ZAKLJUČNO POROČILO O REZULTATIH OPRAVLJENEGA RAZISKOVALNEGA DELA NA PROJEKTU V OKVIRU CILJNEGA RAZISKOVALNEGA PROGRAMA (CRP) »KONKURENČNOST SLOVENIJE 2006 – 2013«

I. Predstavitev osnovnih podatkov raziskovalnega projekta

1. Naziv težišča v okviru CRP:

Konkurenčno gospodarstvo in hitrejša rast - Nacionalna in sektorska konkurenčnost

2. Šifra projekta:

V4-0409

3. Naslov projekta:

Optimiranje proizvodnih postopkov za povečevanje dodane vrednosti v kmetijstvu

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3. Naslov projekta

3.1. Naslov projekta v slovenskem jeziku:

Optimiranje proizvodnih postopkov za povečevanje dodane vrednosti v kmetijstvu

3.2. Naslov projekta v angleškem jeziku:

Production process' optimisation for increasing value added in agriculture

4. Ključne besede projekta

4.1. Ključne besede projekta v slovenskem jeziku:

dodana vrednost, kmetijstvo, optimiranje, Slovenija

4.2. Ključne besede projekta v angleškem jeziku:

value added, agriculture, optimisation, Slovenia

5. Naziv nosilne raziskovalne organizacije:

Univerza v Ljubljani, Biotehniška fakulteta

5.1. Seznam sodelujočih raziskovalnih organizacij (RO):

Kmetijski inštitut Slovenije

6. Sofinancer/sofinancerji:

Ministrstvo za kmetijstvo, gozdarstvo in prehrano

7. Šifra ter ime in priimek vodje projekta:

13487	Stane KAVČIČ

Datum: 2. marec 2010

Podpis vodje projekta:

Prof. dr. Stane Kavčič

Podpis in žig izvajalca:

Rektor prof. dr. Radovan Stanislav Pejovnik,
po pooblastilu dekan prof. dr. Franc Štampar

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II. Vsebinska struktura zaključnega poročila o rezultatih raziskovalnega projekta v okviru CRP

1. Cilji projekta:

1.1. Ali so bili cilji projekta doseženi?

- [x] a) v celoti
- [ ] b) delno
- [ ] c) ne

Če b) in c), je potrebna utemeljitev.

1.2. Ali so se cilji projekta med raziskavo spremenili?

- [ ] a) da
- [x] b) ne

Če so se, je potrebna utemeljitev:

2. Vsebinsko poročilo o realizaciji predloženega programa dela[1]:

Deregulacija kmetijskih trgov vzporedno s pričakovanim postopnim umikom SKP, rastoče okoljske in družbene zahteve ter klimatske spremembe vodijo v vedno večja tržna nihanja, ki jih spremlja profesionalizacija kmetijstva. Gospodarski subjekti so zato čedalje bolj izpostavljeni proizvodnim in poslovnim tveganjem, to pa od njih zahteva prilagoditev poslovanja in učinkovitejše načrtovanje gospodarjenja. Ob intenzivnih strukturnih spremembah kmetijske pridelave v EU kot odziva na politično dogovorjene obveznosti (naklonjenost Komisije bioenergetiki in vse večji ne-prehranski uporabi žit) lahko pričakujemo postopno ponovno povečano povpraševanje po surovinah kmetijskega izvora in posledično dolgotrajnejše zvišanje cen večine pomembnejših poljedelskih kultur na ravni, ki bo višja kot v predkriznem obdobju. To naj bi v povprečnem letu tudi vsaj deloma izboljšalo ekonomski položaj kmetijstva. Na večini slovenskih kmetij pa se žita uporabljajo kot vhodna surovina (v živinorejski proizvodnji), zato v tem sektorju lahko pričakujemo dodatne zaostritve z vidika ekonomike. Spremenljivi stroški krmnega obroka se v govedoreji že danes gibljejo med 40 in 75 % skupnih spremenljivih stroškov reje, pri neprežvekovalcih pa je ta delež lahko tudi višji. Zato vodenje prehrane postaja ključni vzvod za uspešno in ekonomično rejo živali.
Rejci bodo pri načrtovanju krmnih obrokov v prihodnje prisiljeni upoštevati vse večje število ciljev in dodatnih omejitev, s kakršnimi se do sedaj neposredno večinoma še niso srečali (Tozer in Stokes, 2001), jih pa lahko povzamemo z ekonomskim pojmom eksternalije. Tudi v živinoreji lahko pričakujemo razvoj v smeri zaostrenih zakonodajnih zahtev, kakršne v rastlinski pridelavi poznamo že nekaj let (izravnana bilanca hranilnih snovi: zahteve kolobarja, gnojilni načrti, obtežba površin ipd.). V živinoreji nedvomno postaja čedalje pomembnejša zahteva čim manjše obremenjevanje okolja z neizkoriščenimi hranili in minerali. Na področju navzkrižne skladnosti med pogoji dobrega počutja živali v prihodnje lahko pričakujemo večji poudarek tudi zagotavljanju ustrezno uravnoteženega krmnega obroka in minimiziranju možnosti za preskromno ali prekomerno oskrbo s hranljivimi snovmi. Predvsem neuravnoteženost v oskrbi z rudninskimi snovmi pogosto vodi do presnovnih bolezni in drugih anomalij, kar ne vpliva le na slabše počutje živali, ampak ima tudi negativne ekonomske posledice.
Ob poudarjeni »multifunkcionalni« vlogi kmetijstva to prevzema tudi vse značilnosti drugih gospodarskih sektorjev, med katerimi postaja prilagajanje konkurenčnosti temeljni vzrok in vzvod izboljšav v proizvodnji. Proces odločanja na mikro (kmetijska gospodarstva), mezo (raven regionalnega svetovanja) in tudi makro ravni (nosilci odločanja v kmetijski politiki) je mogoče podpreti z razvojem primernih empiričnih orodij. Empirično orodje mora omogočiti simuliranje kompleksnih agro-tehničnih, okoljskih in ekonomskih razmer ter zadostiti kriterijem formalne optimizacije, ki gospodarskim subjektom v danih razmerah z različnih vidikov ovrednoti njihovo razvojno perspektivnost. Tem kriterijem v največji meri zadostijo različne metode in modeli matematičnega programiranja, ki spadajo na področje operacijskih raziskav.

Metodika izvedenega projekta:

Projekt je zasnovan modularno, posamezni moduli pa se medsebojno dopolnjujejo oziroma služijo kot podporna orodja preostalim modulom.

Modul prilagodljivih modelnih kalkulacij za podporo ekonomsko-tehnoloških izračunov (modul 1)

Tako z ekonomskega kot s tehnološkega vidika je zgrajeno orodje podprto z Modelnimi

[1] Potrebno je napisati vsebinsko raziskovalno poročilo, kjer mora biti na kratko predstavljen program dela z raziskovalno hipotezo in metodološko-teoretičen opis raziskovanja pri njenem preverjanju ali zavračanju vključno s pridobljenimi rezultati projekta.

kalkulacijami, razvitimi na Kmetijskem inštitutu Slovenije (Rednak, 1997).

Modelne kalkulacije so samostojni simulacijski modeli, ki na podlagi opredeljenih (izbranih) vhodnih tehnoloških parametrov omogočajo oceno porabe proizvodnih vložkov in s tem stroškov proizvodnje pri posameznih kmetijskih proizvodih. Poraba vložkov je odvisna od intenzivnosti (pridelka), velikosti parcele ali črede, oddaljenosti, nagiba in ponekod še od nekaterih drugih tehnoloških parametrov. Za razliko od t.i. Kataloga kalkulacij (Jerič, 2001), ki je bil osnova pri razvoju podobnega, sicer bistveno manj kompleksnega optimizacijskega orodja v okviru projekta CRP-V4-0362, modelne kalkulacije po posameznih pridelkih neposredno vključujejo vse proizvodne stroške. S tem je omogočen tudi neposreden izračun polne lastne cene. Njihova prednost je tudi v tem, da količine posameznih vložkov v modelnih kalkulacijah niso določene po razredih intenzivnosti, temveč večinoma v obliki funkcijske odvisnosti (zvezno). To je še posebno pomembno pri optimiranju konkretnih kmetijskih gospodarstev, saj je paleta intenzivnosti na slovenskih gospodarstvih zelo pestra. Na Kmetijskem inštitutu Slovenije so za potrebe posodabljanja modelnih kalkulacij vzpostavili tudi interno bazo podatkov za vse parametre (cene inputov in pridelkov, plače, dajatve, proračunske podpore...), katere vse od leta 1994 mesečno posodabljajo. Z uporabo modelnih kalkulacij je zagotovljena aktualnost zgrajenega orodja (enostavno posodabljanje) in tudi verodostojnost vhodnih, s tem pa tudi izhodnih podatkov. Razvito orodje je zato primerno tudi za analizo aktualnega dogajanja na konkretnih kmetijskih gospodarstvih.

Modul za izračunavanje prehranskih potreb (modul 2)

Ta modul temelji na nadgradnji in nadaljnjem razvoju deloma že predhodno pripravljenega modela za izračunavanje potreb po hranilnih snoveh prežvekovalcev (Žgajnar in sod., 2007). V prihodnje bi ga lahko razširili tudi v smeri izračunavanja potreb za neprežvekovalce, vendar to področje ni tako strokovno zahtevno kot pri prežvekovalcih, zato nam ni predstavljal raziskovalnega izziva. Je pa ekonomika reje zaradi velikega deleža žit in močne krme v obroku še toliko občutljivejša na močna nihanja cen teh komponent obroka, ki jih rejci pogosto kupujejo. Optimizacija prehrane zanje lahko pomeni precejšnje znižanje stroškov in s tem izboljšanje ekonomskega položaja, kar smo na nekaterih primerih upoštevali v naslednjem modulu (področje prehrane prašičev).

Modul za izračunavanje prehranskih potreb je izdelan tako, da omogoča izračun povprečnih dnevnih potreb, potreb na točno določen dan znotraj proizvodne dobe, potreb v definiranem obdobju sezone, potreb v celotnem obdobju pitanja ali vzreje oziroma v enem letu glede na vnaprej definirane proizvodne lastnosti. Na podlagi slednjih model izračuna tudi predvideno dobo vzreje plemenskih živali in živali v pitanju. S takšnim pristopom je omogočeno obravnavanje različnih tehnologij reje in vzreje, s katerimi se v praksi srečujemo. Posebna pestrost tehnologij je prisotna pri govejih pitancih, pri katerih se ta odraža poleg pestre pasemske strukture predvsem v različnih začetnih masah pitanja in intenzivnosti pitanja. To se odraža tako v povprečnem dnevnem prirastu, dobi pitanja, kot tudi v klavno zreli telesni masi.

V okviru tega modula smo pripravili tudi nabor najpogosteje uporabljene krme in njene hranilne vrednosti. To omogoča predvsem enostavne in hitre analize posameznega kmetijskega gospodarstva, saj lahko na osnovi nekaj najpomembnejših standardnih parametrov približno ocenimo hranilno vrednost doma pridelane krme.

Prednost zgrajenega modula za izračunavanje prehranskih potreb je tudi ta, da od potencialnih uporabnikov ne zahteva podrobnega poznavanja uporabljenih funkcijskih pristopov, pač pa le nekatere bistvene zakonitosti živinoreje in pridelovanja krme. Hkrati je enostaven in dovolj natančen izračun krmnih potreb edini način, s katerim lahko rejce prepričamo v smiselnost pogostejšega izračunavanja obrokov za njihove živali.

Modul za optimiranje prehrane z več pod-moduli (modul 3)

Pri izgradnji tega modula smo izhajali iz predpostavke, da je iskanje najcenejšega krmnega obroka, ki hkrati pokrije vse potrebe živali, temeljno vodilo vsakega sodobnega živinorejca. Temu v prid govori dejstvo, da stroški krmnega obroka pogosto presegajo polovico, ob visokih cenah krmnih žit pa pri nekaterih kategorijah živali celo dve tretjini skupnih spremenljivih stroškov. S primernim optimizacijskim programom zato lahko sestavimo cenejše krmne obroke, ki so v danih ekonomskih in tržnih pogojih za posamezno rejo ekonomsko najugodnejši. S pomočjo tehnik matematičnega programiranja smo znotraj tega modula razvili samostojna optimizacijska orodja, s pomočjo katerih je možna optimizacija krmnih obrokov za posamezno kategorijo živali. V okviru projekta smo tako pripravili optimizacijski model za optimiranje prehrane krav molznic, krav dojilj, bikov pitancev in prašičev pitancev.

Za vse omenjene kategorije domačih živali smo ubrali podoben metodološki pristop, bistvene razlike nastopijo le pri optimiranju prehrane prašičev pitancev. Modele smo zasnovali na principu dvostopenjske optimizacije, ki temelji na principu dveh podmodelov (Žgajnar in Kavčič, 2008). Prvi pod-model temelji na metodi klasičnega linearnega programiranja. Z njim iščemo najcenejši krmni obrok, ki v 'grobem' zagotavlja pokrivanje prehranskih potreb, izračunanih s prejšnjim modulom. Pri iskanju rešitve upošteva le najpomembnejše omejitve, saj se zlasti pri visoko-produktivnih živalih, zaradi poenostavitev (linearni odnosi) ter nasprotujočih se omejitev, lahko zgodi da sistem nima rešitve. Posledično to pomeni da je sistem enačb, s katerimi je opredeljen prehranski problem, relativno precej 'odprt', kar nekaterih primerih pripelje tudi do prevelikih odstopanj od ključnih normativov. Posledično je lahko dobljena rešitev za prakso neuporabna (prevelike prekoračitve posameznih parametrov krmnih obrokov in neustrezna razmerja med hranilnimi snovmi). Problem bi deloma lahko zaobšli z definiranjem novih omejitev, s katerimi bi preprečili prekomerne prekoračitve, vendar bi takšen pristop zahteval interaktivni pristop reševanja, ki pa zardi zahtevanega znanja ter tudi časa reševanja ni zanimiv. Poleg tega bi takšen pristop pomenil zelo 'zaprt sistem enačb', ki bi se pri visoko-produktivnih živalih še pogosteje izkazal kot nerešljiv.

Pri ubranem pristopu je pomen linearnega programiranja poiskati najcenejši krmni obrok, pri katerem nas ne zanima sestava samega obroka pač pa podatek o ceni. Slednjo namreč potrebujemo v drugem pod-modelu, ki temelji na tehtanem ciljnem programiranju in dodatno nadgrajenem s kazensko funkcijo. Gre za metodo večkriterijskega programiranja, ki na podlagi večjega števila ciljev poišče optimalno rešitev. Torej s tem pristopom iščemo kompromisno rešitev med zastavljenimi cilji, vključno z izračunanim minimalnim stroškom krmnega obroka, kateremu se poskušamo približati. Dodana t.i. 'kazenska funkcija' pa nam omogoča, da tudi v skrajnih primerih lahko pridemo do smiselne rešitve. Z njo definiramo dovoljena odstopanja od postavljenih omejitev. Namreč ena izmed ključnih pomanjkljivosti tehtanega ciljnega programiranja je da ne razlikuje med mejnimi spremembami oziroma ne loči med obsegom odstopanj od posameznih ciljev. S prehranskega vidika to pomeni, da dobimo prehransko bolj uravnotežen krmni obrok, ki pa se po stroškovni strani minimalno razlikuje od najcenejšega možnega, ki bi teoretično zagotavljal doseganje zastavljene proizvodnosti živali, v praksi pa pri njihovem doslednem upoštevanju zaradi porušenih medsebojnih razmerij tega pogosto ne dosegamo.

Na ta način izračunani krmni obroki (bodisi dnevni/mesečni/polletni/letni) lahko vstopajo nazaj v živinorejske modelne kalkulacije. S tem vsaj teoretično lahko zagotovimo njihovo večjo fleksibilnost - prilagodljivost analiziranemu primeru. Vendar tega postopka ni mogoče popolnoma avtomatizirati, se je pa s pomočjo takšnega pristopa mogoče bolj približati stanju na konkretnem kmetijskem gospodarstvu. V primeru uporabe orodja za pomoč pri vodenju konkretnega kmetijskega gospodarstva lahko na ta način vnaprej ocenimo, katere kulture so za konkretno kmetijsko gospodarstvo v danih pogojih najbolj donosne. Uporabnik bi tako lahko svoje proizvodne vire razporedil tako, da bi kar najbolje pokril potrebe svojih živali. Prav alokacijska učinkovitost pa je poleg tehnične učinkovitosti ključen element ekonomske učinkovitosti (Farrell, 1957).

Pri uporabljenem pristopu gre za podporo kratkoročnim odločitvam, ki pa pogosto lahko podkrepijo dolgoročno načrtovanje in usmeritev kmetijskih gospodarstev. Optimizacija prehrane lahko pomeni precejšnje znižanje stroškov in s tem izboljšanje ekonomskega položaja. V prihodnje bi kazalo uporabljen pristop razširiti na dodatne živinorejske aktivnosti in ga s tem približati večjemu številu kmetijskih gospodarstev v Sloveniji.

Modul za optimiranje kmetijskih gospodarstev (modul 4)
Za podporo pri odločanju na ravni kmetijskih gospodarstev v Sloveniji je bil že razvit deterministični statični linearni program v okviru projekta »Spletni informacijski sistem za podporo odločanju na kmetijskih gospodarstvih« (CRP-V4-0362). Optimizacija je izvedena po načelu maksimiranja skupnega doseženega pokritja na ravni kmetije, ki jo opredelimo preko vnosa precej obširnega nabora podatkov in izklapljanja tistih aktivnosti, ki na konkretnem gospodarstvu niso realna alternativa. Model temelji na podatkih iz Kataloga kalkulacij. Kot je bilo že omenjeno, ima takšen pristop pomanjkljivost predvsem z vidika posodabljanja cenovnih razmerji in nezveznosti vključenih aktivnosti. To se je izkazalo kot pomanjkljivost tudi v fazi testiranja optimizacijkega modula (CRP-V4-0362). Zato smo v okviru tega projekta optimizacijski model nadalje razvili v smislu enostavnejšega posodabljanja kot tudi vklapljanja novih aktivnosti. Za precejšen del proizvodnih parametrov, stroškov in prihodkov smo pripravili izračune, ki preko funkcijskih povezav oblikujejo matriko za načrtovanje na konkretnem kmetijskem gospodarstvu. Formiranje matrike še vedno temelji na pokritjih, naknadno pa je mogoče od dobljene rešitve odšteti ocenjeno vsoto stalnih stroškov ali pa te izračunati na podlagi modelnih kalkulacij. Tak pristop omogoča podrobnejšo finančno analizo konkretnega kmetijskega gospodarstva.
Zaradi krčitve finančnih sredstev projekta tega koraka nismo izpeljali do faze, da bi bil celoten preračun avtomatiziran, bi pa bil takšen postopek tudi z vidika potrebne strojne opreme (zmogljivosti računalnika) razmeroma zahteven, saj bi bil potreben iterativni pristop, torej večkratni zagon optimizacije, da bi dobili optimalno rešitev. Z vidika končnega uporabnika pa bi to pomenilo pristop, ki bi zagotovo večino odvrnil od njegove uporabe.
V prehranskem delu razširjen in natančnejši model omogoča tudi dodatne analize s področja ekonomike prehrane. S ponovnim definiranjem namenske funkcije smo naredili tudi primerjalno analizo med optimalno rešitvijo, ki jo dobimo pri maksimiranju pokritja in med optimalno rešitvijo, če z namensko funkcijo minimiramo krmne stroške. Ugotovili smo, da je ob istih omejitvah korelacija med dobljenimi rešitvami zelo visoka.

Za izvedbo projekta smo uporabili predvsem metode matematičnega programiranja. Zaradi modularnega pristopa k izvedbi projekta smo lahko uporabili njim najbolj ustrezne metode. Na podlagi pregleda literature smo izbirali med metodami matematičnega programiranja, ki so bile vsaj teoretično predhodno že aplicirane za različne obratoslovne probleme. V modulih, kjer je izvedena formalna optimizacija, smo uporabili tehniko klasičnega determinističnega linearnega programiranja. Pri praktičnem reševanju optimizacijskih problemov pa se skoraj vedno izkaže, da je fokusiranje zgolj na en cilj kot edini in najpomembnejši (ekonomski) pregroba poenostavitev in je posledično dobljena rešitev za prakso povsem neuporabna. Zato smo na podlagi dognanj (Rehman in Romero, 1984, 1987; Lara, 1993; Lara in Romero, 1994 in kasneje tudi drugih) probleme skušali streti s pomočjo večkriterialnega pristopa in iskali rešitev, ki nam ne omogoča le ekonomske optimizacije, ampak ob tem zasleduje tudi druge cilje, ki so prav tako pomembni za načrtovanje odločitve (Zadnik Stirn, 2001).
V okviru projekta smo tako pri nekaterih modulih uporabili tehtano ciljno programiranje. Gre za posebno obliko linearnega programiranja. V primerjavi s klasičnim linearnim programom, kjer naenkrat lahko optimiramo le en cilj, ostale zahteve pa zajamemo v omejitvah, lahko s ciljnim programom iščemo rešitev, ki zadosti večjemu številu zastavljenih ciljev. Želene toge omejitve klasičnega linearnega programa tako preoblikujemo v cilje. Dosežemo jih lahko v celoti, deloma, v skrajnih primerih pa nekaterih izmed njih sploh ne dosežemo. Metoda torej dopušča odstopanje od

zastavljenega cilja, ki pa naj bi bilo čim manjše. Zagotovo je namreč v praksi bolje, da dobimo »dovolj dobro« rešitev, kot pa da dobimo optimalno in povsem nerealno oziroma je sploh ne dobimo.
Nadgrajen klasičen linearni program v ciljni program omogoča večjo fleksibilnost in v večini primerov pripelje do realnejše rešitve. Z njim minimiziramo neželeno odstopanje od zastavljenih ciljev in ne minimiziramo oziroma maksimiramo ciljev samih (Ferguson in sod., 2006). Kvaliteta modela je tako v največji meri odvisna od definiranja zastavljenih ciljev in pripadajočih uteži k posameznemu cilju. Zato je pri večkriterialnem modeliranju nujno sodelovanje strokovnjakov iz vpletenih področij ali celo uporaba druge metode za čim manjšo pristranskost pri definiranju pomena posameznega cilja. Za definiranje uteži bi namreč lahko uporabili metodo analitičnega hierarhičnega procesa (AHP). Ta se je pri reševanju večkriterialnih problemov že izkazala kot učinkovito orodje pri definiranju uteži ciljev. V zgrajenih modulih tega projekta pa ta metoda še ni bila uporabljena.
Z uporabo tehnike ciljnega programiranja pridemo do kompromisne rešitve, ki pa vsaj v nekaterih primerih lahko pomeni preveliko odstopanje od zastavljenega cilja in zato iz praktičnega vidika takšna rešitev ni sprejemljiva. Da smo prehranske potrebe živali ohranili znotraj želenih mej, smo ciljni program nadgradili s t.i. kazensko funkcijo (Rehman in Romero, 1984). Vsako odstopanje od želenega cilja (želimo ga doseči 100 %) smo na ta način obravnavali po vnaprej definirani večstopenjski kazenski lestvici, ki ni dopuščala večjega odstopanja od meje definiranih intervalov. Namenska funkcija tehtanega ciljnega programiranja, nadgrajenega s kazensko funkcijo, je na ta način merila celotno 'kazen', pridobljeno z odstopanji od posameznih ciljev. Intervale kazenske lestvice, s katerimi smo definirali dovoljeno odstopanje od zastavljenih ciljev, pa smo vključili v nabor omejitev.

Rezultati:
Operativni cilj izvedenega projekta je aplikacija metode matematičnega programiranja za reševanje problemov večkriterijskega odločanja na ravni kmetijskih gospodarstev.
Večji del raziskovalnega dela, opravljenega v okviru projketa, je bilo predstavljeno v obliki prispevkov na šestih znanstvenih konferencah (od tega štiri na mednarodni ravni, eden na svetovni ter eden na nacionalni ravni) in v mednarodnih znanstvenih revijah.
Primer optimiranja obrokov za bike pitance ter opis uporabljenga pristopa je podrobno predstavljen v Žgajnar in Kavčič (2008b) ter Žgajnar in Kavčič (2008c). Metodološko podoben pristop je bil apliciran tudi na primeru sestavljanja obrokov za krave molznice (Žgajnar in Kavčič, 2009d; Žgajnar in sod. 2009), kjer je bil poudarek na formuliranju dnevnih krmnih obrokov. Pri sestavljanju ter analiziranju prehrane prašičev pitancev je bil uporabljen metodološko podoben pristop, ki pa je temeljil na treh pod-modelih (Žgajnar in Kavčič, 2009a; Žgajnar in Kavčič, 2009b in Žgajnar in Kavčič, 2009c). Pri slednjih se je namreč izkazalo, da je ekonomičnost reje - tehnologije pitanja zelo odvisna od energetske koncentracije obroka. Zadnji korak pa na podlagi preprostega algoritma izbere najučinkovitejšo rešitev.
Na primeru pitanja bikov smo analizirali tudi, kako 'zunanje' spremembe na političnem in ekonomskem področju prispevajo k izrazito poslabšani stabilnosti ekonomike pitanja govedi (Žgajnar in Kavčič, 2008a). Naša hipoteza je bila, da se z zviševanjem cen krme (poslabšanje cenovno-stroškovnih razmerij) kot posledice dodatnega povpraševanja (bio-energija, bio-masa), manjše proizvodnje in liberalizacije trgov, spreminja tudi (racionalna) sestava krmnega obroka. Analizo smo opravili s pomočjo metod matematičnega programiranja, ki temeljijo na principu omejene optimizacije. Za simuliranje odzivov na zunanje (eksogene) spremembe je bila uporabljena metoda pozitivnega matematičnega programiranja (PMP).

V okviru projekta razvito modularno orodje povezuje številne dejavnike, ki so predmet različnih področij in skupaj krojijo kratkoročno odločanje in dolgoročno načrtovanje kmetijskih gospodarstev, s poudarkom na prehrani. To je namreč podočje, kateremu je

bilo v dosedanjih agrarno-ekonomskih raziskavah posvečeno (pre)malo pozornosti, je pa ključno pri analizi živinorejskih tipov kmetijskih gospodarstev. Orodje je ob vključitvi najsodobnejših tehnik linearnega programiranja razdelano do te mere, da omogoča simulacijo realnih rezultatov in je zato lahko v dejansko pomoč pri obratoslovnih odločitvah.
Zaradi kompleksnosti dejavnosti kmetijstva je bilo delo ob upoštevanju časovnih, človeških in finančnih omejitev projekta omejeno le na del gospodarskih aktivnosti in s tem prilagojeno za odločanje na določenem tipu kmetijskih gospodarstev. Model lahko apliciramo na kmetijska gospodarstva, ki se ukvarjajo predvsem z rejo prežvekovalcev. Orodje omogoča razrešitev nekaterih vprašanj nadaljnje profesionalizacije, proizvodne preusmeritve, izbire ukrepov kmetijske politike ter trajnostne rabe proizvodnih virov na ravni tovrstnih kmetijskih gospodarstev. Z morebitnim podaljšanjem projekta bi zgrajeno orodje lahko nadgradili v smeri večje univerzalnosti (dopolnjevanje z dodatnimi usmeritvami: neprežvekovalci, dodatne poljedelske kulture, trajni nasadi, zelenjadarstvo ipd.).
Z izvedbo projekta smo omogočili izboljšave posameznih korakov načrtovanja na mikro in mezo ravni. V prvi vrsti z zgrajenim orodjem lahko optimiramo proizvodnjo na konkretnih kmetijskih gospodarstvih, na podlagi rezultatov tipičnih kmetijskih gospodarstev znotraj izbranih regij pa ima orodje napovedovalno moč tudi za simulacije razvojnih učinkov na regionalni in nacionalni ravni.

3. Izkoriščanje dobljenih rezultatov:

3.1. Kakšen je potencialni pomen[2] rezultatov vašega raziskovalnega projekta za:

- ☐ a) odkritje novih znanstvenih spoznanj;
- ☒ b) izpopolnitev oziroma razširitev metodološkega instrumentarija;
- ☒ c) razvoj svojega temeljnega raziskovanja;
- ☐ d) razvoj drugih temeljnih znanosti;
- ☐ e) razvoj novih tehnologij in drugih razvojnih raziskav.

3.2. Označite, s katerimi družbeno-ekonomskimi cilji (po metodologiji OECD-ja) sovpadajo rezultati vašega raziskovalnega projekta:

☒ a) razvoj kmetijstva, gozdarstva in ribolova - Vključuje RR, ki je v osnovi namenjen razvoju in podpori teh dejavnosti;

☐ b) pospeševanje industrijskega razvoja - vključuje RR, ki v osnovi podpira razvoj industrije, vključno s proizvodnjo, gradbeništvom, prodajo na debelo in drobno, restavracijami in hoteli, bančništvom, zavarovalnicami in drugimi gospodarskimi dejavnostmi;

☐ c) proizvodnja in racionalna izraba energije - vključuje RR-dejavnosti, ki so v funkciji dobave, proizvodnje, hranjenja in distribucije vseh oblik energije. V to skupino je treba vključiti tudi RR vodnih virov in nuklearne energije;

☐ d) razvoj infrastrukture - Ta skupina vključuje dve podskupini:

- transport in telekomunikacije - Vključen je RR, ki je usmerjen v izboljšavo in povečanje varnosti prometnih sistemov, vključno z varnostjo v prometu;
- prostorsko planiranje mest in podeželja - Vključen je RR, ki se nanaša na skupno načrtovanje mest in podeželja, boljše pogoje bivanja in izboljšave v okolju;

☒ e) nadzor in skrb za okolje - Vključuje RR, ki je usmerjen v ohranjevanje fizičnega okolja. Zajema onesnaževanje zraka, voda, zemlje in spodnjih slojev, onesnaženje zaradi hrupa, odlaganja trdnih odpadkov in sevanja. Razdeljen je v dve skupini:

☐ f) zdravstveno varstvo (z izjemo onesnaževanja) - Vključuje RR - programe, ki so usmerjeni v varstvo in izboljšanje človekovega zdravja;

☐ g) družbeni razvoj in storitve - Vključuje RR, ki se nanaša na družbene in kulturne probleme;

☐ h) splošni napredek znanja - Ta skupina zajema RR, ki prispeva k splošnemu napredku znanja in ga ne moremo pripisati določenim ciljem;

☐ i) obramba - Vključuje RR, ki se v osnovi izvaja v vojaške namene, ne glede na njegovo vsebino, ali na možnost posredne civilne uporabe. Vključuje tudi varstvo (obrambo) pred naravnimi nesrečami.

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[2] Označite lahko več odgovorov.

3.3. Kateri so **neposredni rezultati** vašega raziskovalnega projekta glede na zgoraj označen potencialni pomen in razvojne cilje?

Olajšani so določeni postopki načrtovanja prehrane na kmetijskih gospodarstvih, predvsem izračunavanja obrokov za različne kategorije domačih živali. Izračunavanje obrokov temelji na razpoložljivi krmi in potrebah živali, bistveni prispevek tega projekta pa je optimiranje tehnologije prehrane živali, ki je podkrepljeno z ekonomskimi izračuni. Na ta način je omogočena časovna/delovna razbremenitev kmetijskih gospodarjev, predvsem pa izračunani obroki omogočajo skozi vgrajeno stroškovno optimizacijo doseganje višje dodane vrednosti v živinorejski proizvodnji, vendar nikakor ne na škodo okolja.

3.4. Kakšni so lahko **dolgoročni rezultati** vašega raziskovalnega projekta glede na zgoraj označen potencialni pomen in razvojne cilje?

Razvoj orodij matematičnega programiranja v smeri, ki je precej prijazen do uporabnikov, omogoča prenos teoretičnih dognanj v vsakodnevno prakso kmetovanja in na daljši rok omogoča preko dviga dodane vrednosti (skozi večjo stroškovno učinkovitost) izboljšanje konkurenčnosti slovenskega kmetijstva.
Ker razvita orodja omogočajo bolj natančno izravnavo zaužitih in potrebnih hranilnih snovi v obrokih (domačih vrst) živali, z uporabo razvitih orodij lahko dosežemo tudi pozitivne okoljske učinke (manjše izločanje neizkoriščenih hranilnih snovi v okolje, manjši izpusti toplogrednih plinov na enoto prireje ipd.).

3.5. Kje obstaja verjetnost, da bodo vaša znanstvena spoznanja deležna zaznavnega odziva?

- ☒ a) v domačih znanstvenih krogih;
- ☒ b) v mednarodnih znanstvenih krogih;
- ☒ c) pri domačih uporabnikih;
- ☐ d) pri mednarodnih uporabnikih.

3.6. Kdo (poleg sofinancerjev) že izraža interes po vaših spoznanjih oziroma rezultatih?

Neposredni uporabniki (predvsem mlajši kmetijski gospodarji) in Kmetijsko-gozdarska zbornica Slovenije.

3.7. Število diplomantov, magistrov in doktorjev, ki so zaključili študij z vključenostjo v raziskovalni projekt?

v fazi izdelave je ena diplomska naloga in ena doktorska disertacija. Prva predstavlja primer neposredne uporabe razvitih orodij v praksi (z iskanjem izboljšav v drugih fazah proizvodnih postopkov na kmetiji), druga pa znanstveno-metodološko poglobitev dela na področju optimizacije odločanja na kmetijskih gospodarstvih.

4. Sodelovanje s tujimi partnerji:

4.1. Navedite število in obliko formalnega raziskovalnega sodelovanja s tujimi raziskovalnimi inštitucijami.

Pri projektu, ki je predmet tega zaključnega poročila, nismo imeli formalnega raziskovalnega sodelovanja s tujimi raziskovalnimi inštitucijami.

4.2. Kakšni so rezultati tovrstnega sodelovanja?

Ta točka za ta projekt ni relevantna.

5. Bibliografski rezultati[3] :

Za vodjo projekta in ostale raziskovalce v projektni skupini priložite bibliografske izpise za obdobje zadnjih treh let iz COBISS-a) oz. za medicinske vede iz Inštituta za biomedicinsko informatiko. Na bibliografskih izpisih označite tista dela, ki so nastala v okviru pričujočega projekta.

6. Druge reference[4] vodje projekta in ostalih raziskovalcev, ki izhajajo iz raziskovalnega projekta:

/

[3] Bibliografijo raziskovalcev si lahko natisnete sami iz spletne strani:http:/www.izum.si/

[4] Navedite tudi druge raziskovalne rezultate iz obdobja financiranja vašega projekta, ki niso zajeti v bibliografske izpise, zlasti pa tiste, ki se nanašajo na prenos znanja in tehnologije.
Navedite tudi podatke o vseh javnih in drugih predstavitvah projekta in njegovih rezultatov vključno s predstavitvami, ki so bile organizirane izključno za naročnika/naročnike projekta.

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STANKO KAVČIČ [13487]
Osebna bibliografija za obdobje 2007-2010

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SPREMEMBE SESTAVE KRMNIH OBROKOV ZA GOVEJE PITANCE

PRIMER UPORABE NORMATIVNIH IN POZITIVNIH MATEMATIČNIH METOD

Jaka ŽGAJNAR [a], Stane KAVČIČ [b]

[a] Univ. v Ljubljani, Biotehniška Fak., Odd. za zootehniko, Groblje 3, SI-1230 Domžale, Slovenija, e-mail: jaka.zgajnar@bfro.uni-lj.si.
[b] Isti naslov kot [a], prof

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IZVLEČEK

Namen prispevka je prikazati možnost kombiniranja različnih matematičnih metod za analiziranje sestave krmnih obrokov v danih okoliščinah. Z matematičnimi modeli, ki temeljijo na omejeni optimizaciji, smo proučevali cenovno-stroškovna razmerja v obdobju 1998 do 2008 in iskali morebitne spremembe v sestavi racionalnih krmnih obrokov za goveje pitance. Za analizo smo uporabili normativne in pozitivne matematične metode. S pomočjo klasičnega linearnega programa, nadgrajenega s tehtanim ciljnim programom, smo izvedli normativno analizo. Da bi ugotovili, kako bi se v danih razmerah odločal povprečen rejec, pa smo simulacijo izvedli tudi s pozitivnim matematičnim programiranjem. Dobljeni rezultati kažejo, da se je sestava racionalnega krmnega obroka v zadnjih desetih letih nagnila v prid koruzne silaže, izrazito pa se je zmanjšala količina travne silaže v obroku. Zaradi naravnih danosti v Sloveniji take spremembe niso izvedljive, zato bomo morali več pozornosti posvetiti zniževanju stroškov pridelave travne silaže.

Ključne besede: linearno programiranje, tehtano ciljno programiranje, PMP, krmni obrok, biki pitanci

CHANGES OF BEEF RATION COMPOSITION

AN EXAMPLE OF UTILIZING NORMATIVE AND POSITIVE MATHEMATICAL METHODS

ABSTRACT

The aim of this paper is to present possibility to combine different mathematical methods for analysis of ration composition changes in actual economic environment. On the basis of mathematical programming models, based on constraint optimization, the influence of price-cost ratios on the trends of efficient beef ration formulation in the period 1998 to 2008 has been analysed. For investigation positive and normative mathematical methods have been utilized. The normative part of methods applies a common linear programming approach supported by penalty function. To find out the "reaction" of rational farmer within given circumstances, simulation was upgraded with positive mathematical programming approach. Obtained results illustrate change in ration composition by increased maize silage quantities and significantly lower amounts of grass silage during last decade. Due to Slovene natural conditions it is obvious that such a dramatic shift is impossible, therefore more attention should be paid to reduction of grass silage production costs.

Key words: linear programming, weighted goal programming, PMP, ration, beef fattening

UVOD

Spremembe na političnem in ekonomskem področju so v zadnjem času prispevale k izrazito poslabšani stabilnosti ekonomike pitanja govedi. K temu je botrovalo več t.i. 'notranjih', kot tudi 'zunanjih' dejavnikov. V prvi vrsti lahko 'krivca' iščemo v reformi skupne kmetijke politike (SKP). Korenitejši preobrat je nakazala že MacSharrijeva reforma v letu 1992, ki odpravlja dobršen del tržno izkrivljajočih ukrepov (intervencijske cene) in daje poudarek neposrednim plačilom. Agenda 2000 z nadaljnjim zniževanjem cen in dvigom neposrednih plačil v duhu predhodne reforme je ta zasuk še stopnjevala. Za obravnavan sektor je prinesla z dohodkovnega vidika zanimive klavne premije in z njimi omilila vse slabšo ekonomsko situacijo, ki jo prinaša liberalizacija trga z govejim mesom. Zadnja, t.i. Fischlerjeva reforma, v Sloveniji vpeljana v letu 2007, pa je uvedla do tedaj še ne poznan pojem proizvodne nevezanosti plačil. Kljub vsemu je zaradi občutljivosti sektorja del plačil ostal proizvodno vezan (60 % posebne premije, premija za ekstenzivno rejo ženskih živali). Takšna politika naj bi s poudarjeno liberalizacijo kmetijskih trgov vodila do večje tržne orientiranosti kmetijstva. Slednja se vsaj zaenkrat odraža v bistveno poslabšani ekonomski situaciji pitanja govedi, saj odkupne cene ne sledijo trendu rasti stroškov. Rešitve najbrž bolj kot na prihodkovni lahko iščemo na stroškovni strani pitanja, saj so tu možnosti vplivanja rejcev številnejše.

V opazovani panogi imamo dve ključni stroškovni postavki, nakup teleta in nakup ali pridelava krme. Dokaj pogost primer v Sloveniji je, da rejci kupujejo teleta. Nakupna cena slednjih je po podatkih Kmetijskega inštituta Slovenije (KIS) v zadnjih štirih letih zopet v izrazitem porastu. Prav tako pa so se stroški krmnega obroka v zadnjih letih izrazito povečali (KIS, 2008). Na podlagi rezultatov modelnih kalkulacij KIS smo ocenili, da se stroški krmnega obroka pri pitanju govedi gibljejo na ravni okrog 55 % celotnih stroškov oziroma nekaj manj kot 70 % spremenljivih stroškov reje. Deloma so povišani stroški krme posledica večjega povpraševanja po žitih, ki ji pridelava ne sledi, bodisi zaradi suše in naravnih ujm, ki so v zadnjih letih prizadele strateška območja za pridelavo žit. Po žetvi 2008 pa se lahko opaženi trendi zopet obrnejo, saj se je situacija tako na kmetijskih kot tudi na ostalih trgih spremenila zaradi dobre letine žit in splošne zaostritve gospodarskih razmer zaradi porajajoče recesije nekaterih ključnih nacionalnih gospodarstev v svetovnem merilu.

Naša hipoteza je, da se z zviševanjem cen krme, kot posledice dodatnega povpraševanja (bio-energija, bio-masa), manjše proizvodnje in liberalizacije trgov, spreminja tudi (racionalna) sestava krmnega obroka. Pričakujemo, da so visoke cene žit botrovale višjim oportunitetnim stroškom predvsem energijske krme, kar naj bi imelo za posledico spremembo v sestavi krmnega obroka. Poleg tega vse višji vhodni stroški (npr. mineralna gnojila, gorivo) močno zvišujejo lastno ceno doma pridelane krme, kar v ospredje postavlja ekonomijo obsega (pri večjem obsegu proizvodnje se stroški na enoto zmanjšujejo). Ker konzervirana voluminozna krma pri večini rejcev v Sloveniji predstavlja poglaviten vir hranljivih snovi v krmnem obroku, se zastavlja vprašanje, ali bo izrazitemu porastu cen v preteklih letih sledil tudi preobrat v tehnologiji pitanja. Pričakujemo, da bodo rejci govejih pitancev za doseganje ekonomsko privlačnega rezultata, poleg upoštevanja ekonomije obsega, prisiljeni poiskati tudi nove tehnološke rešitve.

V tem prispevku bomo analizirali, kako naj bi se v preteklem desetletnem obdobju (1998 – 2008) sestava krmnega obroka spreminjala glede na spremembe stroškovno-cenovnih razmerij kupljene in doma pridelane krme. Analize bomo opravili s pomočjo metod matematičnega programiranja, ki temeljijo na principu omejene optimizacije. Tovrstne metode so v zadnjem času postale pomembno orodje za najrazličnejše analize v kmetijstvu in ekonomiki (Buysse in sod., 2007). Gre namreč za pristop, ki zelo dobro združi t.i. neoklasično produkcijsko teorijo z modeliranjem. Omejene vire želimo na čim boljši in čim bolj učinkovit način uporabiti in na ta način optimirati dohodek kmetijskega gospodarstva. Temeljna zamisel je, da bomo z minimiranjem stroškov krme vsako leto dobili nekoliko spremenjen krmni obrok, seveda v odvisnosti od gibanja tržnih cen ter lastnih cen uporabljene krme. Iz sprememb v sestavi krmnih obrokov bomo nato poizkušali potegnili zaključke, kako vse dražja krma vpliva na prilagajanje tehnologije pitanja. Za analizo bomo uporabili tri vrste matematičnih modelov. Z vidika ekonomske teorije jih lahko uvrstimo v skupino normativnih in pozitivnih modelov.

Normativne analize smo se lotili s pomočjo klasičnega linearnega programa (LP). Gre za zelo pogost pristop, ki se na področju agrarne ekonomike uporablja že več kot 50 let. Njegovo uporabo zasledimo pri reševanju najrazličnejših prehranskih problemov, tako na področju humane prehrane, kot pri načrtovanju in vodenju prehrane vseh vrst domačih živali (Darmon in sod., 2002). Če se osredotočimo na področje prehrane domačih živali, lahko ugotovimo, da je najpogosteje LP uporabljen za iskanje najcenejšega obroka. Prvi je ta pristop uporabil Waugh (1951). Kljub temu, da je modeliranje z linearnim programom pogosto ostro kritizirano zaradi svoje normativne narave, pa Jones (1982) podarja, da so modeli tega tipa izrazito dobrodošli v primeru, ko gre za analiziranje odločitev v razmerah, ki so izven obsega preteklih izkušenj in zato razmere ne morejo biti modelirane z bolj pozitivnimi metodami, kot so denimo ekonometrični modeli. Zato bomo v naši analizi uporabili metodo LP, da bi ugotovili, ali bi kmetje v danih ekonomskih razmerah lahko posegali tudi po drugi krmi na trgu, da bi si pocenili stroške pitanja in si na ta način povečali konkurenčnost pitanja.

Drugo, še vedno normativno, analizo smo izvedli s pomočjo orodja, ki temelji na metodi tehtanega ciljnega programiranja (WGP). Številni strokovnjaki (Rehman in Romero 1984, 1987; Lara 1993) namreč opozarjajo na pomanjkljivosti klasičnega LP za načrtovanje krmnih obrokov. Izpostavljajo predvsem matematično togost z vidika namenske funkcije (naenkrat upoštevamo le en cilj), kot tudi z vidika 'fiksnih' omejitev. Metodo WGP sta prva uporabila Charnes in Cooper (1961, cit po Rehman in Romero, 1984). Gre za posebno obliko matematičnega programiranja, ki temelji na LP oziroma je posebna oblika le-tega (Zadnik Stirn, 2001). V primerjavi s klasičnim LP, pri katerem lahko naenkrat optimiramo le en cilj, ostale zahteve pa zajamemo v omejitvah, lahko s ciljnim programiranjem iščemo rešitev, ki zadosti večjemu številu zastavljenih ciljev. Prednost te metode je tudi, da dovoljuje odstopanje od zastavljenih ciljev (omejitev), ki pa naj bi bilo čim manjše. Vickner in Hoag (1998) ugotavljata, da je v orodjih za podporo pri odločanju (DSS) uporaba WGP zaradi omenjenih prednosti pogostejša od LP.

Za simuliranje odzivov na zunanje (eksogene) spremembe, se v literaturi najpogosteje uporabljajo metode pozitivnega matematičnega programiranja (PMP). Metoda je bila razvita z namenom, da zaobide normativne značilnosti klasičnih optimizacijskih modelov, ki temeljijo na metodah matematičnega programiranja (Buysse in sod., 2007). V večji meri se PMP uporablja v sektorskih modelih (Howitt, 2005). V primerjavi z normativnim matematičnim programiranjem (NMP), se pri PMP modelih namenska funkcija prilagodi tako, da model skoraj povsem natančno ponovi referenčno situacijo. To pomeni, da lahko uporabimo informacijo o dejanskih (opazovanih) odločitvah rejca in na tej podlagi simuliramo, kako bi se le-ta odločal v spremenjenih okoliščinah glede na svoje želje in omejitve.

Glavna ideja PMP je torej kalibriranje modela, kjer s pomočjo kalibracijskih omejitev pridemo do dualnih spremenljivk (senčnih cen kalibracijskih omejitev), ki jih nadalje vključimo v nelinearno ciljno funkcijo (Heckelei, 2002). Ta dva postopka sta bistvena za odpravo pomanjkljivosti NMP t.i. 'nezveznega obnašanja' in problema ponovitve referenčne situacije. Seveda takšen model ne more biti uporabljen za iskanje boljše - optimalnejše - rešitve za kmeta, saj PMP predpostavlja, da je njegova 'referenčna' situacija optimalna (Buysse in sod., 2007). Ta pristop torej omogoča, da s spremembo cenovno-stroškovnih koeficientov namenske funkcije simuliramo, kako bi se kmet v danih ekonomskih pogojih odzival. Seveda je ključna predpostavka, da se njegove preference in občutljivost na dražljaje iz okolja v opazovanem obdobju ne spreminjajo.

MATERIAL IN METODE

Linearni model

Analizo vpliva cen krme na sestavljanje krmnih obrokov smo z vidika ekonomske teorije izvedli s pomočjo normativnih in pozitivnih metod. Za potrebe normativne analize smo uporabili že razvito orodje (DSS) za sestavljanje krmnih obrokov bikov pitancev, ki je podrobneje opisano v prispevku Žgajnar in Kavčič (2008). Orodje je zasnovano na t.i. dvostopenjski optimizaciji, ki se izvede s pomočjo dveh pod-modelov. Ta temeljita na metodah matematičnega programiranja in sicer omejene optimizacije. Prvi pod-model je klasičen linearni model in je primer modela, ki temelji na minimiranju stroškov krmnega obroka. Orodje ga vključuje, da lahko čim bolje oceni 'raven' pričakovanih stroškov krme, ki se v drugem pod-modelu vključujejo kot eden izmed ciljev. Drugi pod-model pa temelji na pristopu WGP, ki z vidika prehrane pripelje do - po hranljivih snoveh - bolj uravnoteženega krmnega obroka.

Za namen te analize smo orodje za sestavljanje krmnih obrokov ustrezno prilagodili. Da bi čim popolneje zajeli celotno stroškovno plat, smo namesto spremenljivih stroškov uporabili lastne cene doma pridelane krme in tržne cene za kupljeno krmo. Dodatno smo izvedli tudi post-optimalno analizo pri pod-modelu LP, s pomočjo katere smo prišli do senčnih cen (angl. shadow price) posameznih omejitev. Osredotočili smo se predvsem na potrebe po energiji, beljakovinah in surovi vlaknini. S pomočjo analize občutljivosti smo izračunali meje lastnih cen travne in koruzne silaže ter tržnih cen sojinih tropin in koruznega zrnja, znotraj katerih bi ostala dobljena rešitev nespremenjena.

Simulacijski PMP model

Posebnost kmetijske pridelave je, da je z vidika prilagodljivosti na zunanje dražljaje na kratek rok relativno toga. Z drugimi besedami to pomeni, da od rejcev ne moremo pričakovati, da bodo krmni obrok med leti zaradi spremenjenih cenovnih razmerij močno spreminjali, pač pa ga bodo prilagajali le v manjši meri. Torej gre za neko 'pričakovano' obnašanje rejcev, ki temelji na njihovih osebnih lastnostih (preferencah) in omejitvah, ki jih denimo klasičen LP model ne zajame. Zaradi tega smo v našo analizo vključili tudi preprost simulacijski model, ki je umerjen (skalibriran) po pristopu standardne PMP metode.

Slednjo je uvedel Howitt (1995) in pri simuliranju uporablja tri korake. V prvem koraku je uporabljen klasičen LP model, s pomočjo katerega dobimo senčne cene klasičnih omejitev (λ_1) in senčne cene dodatnih kalibracijskih omejitev (λ_2). V drugem koraku uporabimo senčne cene kalibracijskih omejitev (λ_2) in s pomočjo teorije povprečnih stroškov izpeljemo parametre (α in β) kalibracijske stroškovne funkcije. V zadnjem (tretjem) koraku s pomočjo referenčnih podatkov in izpeljanih stroškovnih parametrov (α in β) definiramo kvadratno stroškovno-ciljno funkcijo. Tako pripravljen model omogoča avtomatsko kalibracijo modela na referenčno situacijo (Howitt, 2005).

Prehranski PMP model, ki smo ga po Howittu (1995) razvili za simuliranje odziva kmetov pri sestavljanju krmnih obrokov na eksogene cenovne spremembe, v matematični obliki zapišemo, kot je prikazano v enačbah (1) do (9).

Korak 1:

$$MaxZ = -c_i x_i \quad \text{tako, da je} \tag{1}$$

$$A_{ij} x_i \le b_j \quad [\lambda_1] \tag{2}$$

$$x_i \le x_i^0 (1+\varepsilon) \quad [\lambda_2] \tag{3}$$

$$x_i \ge 0 \tag{4}$$

Korak 2:

$$\alpha_i = c_i \tag{5}$$

$$\beta_i = \frac{2\lambda_{2i}}{x_i^o} \qquad (6)$$

Korak 3:

$$MaxZ = -(\alpha + 0{,}5\beta x_i)x_i \text{ tako, da je} \qquad (7)$$

$$A_i x_i \leq b_j \qquad [\lambda_1] \qquad (8)$$

$$x_i \geq 0 \qquad (9)$$

Namenska funkcija, definirana z enačbo (1), predstavlja vsoto zmnožkov tržnih cen ($-c_i$) ter polnih lastnih cen ($-c_i$) i-te krme s količino izbrane i-te krme v sestavljenem krmnem obroku. Ker smo pri cenah upoštevali negativen predznak, je posledično namenska funkcija predmet maksimiranja. Druga enačba predstavlja prehranske normative, katerim mora biti zadoščeno, da model najde rešitev. S pomočjo dualnega programa lahko dobimo senčne cene (λ_1) posameznih omejujočih omejitev. V primerjavi s klasičnim linearnim programom smo naš primarni LP model razširili s t.i. kalibracijskimi omejitvami (3). Z njimi model 'prisilimo', da raven izbrane i-te krme (x_i) ne preseže referenčne količine i-te krme, kateri je prišteta zelo majhna vrednost, t.i. perturbacija (ε). Slednja je vpeljana v kalibracijsko omejitev z namenom, da preprečimo linearno odvisnost med klasičnimi omejitvami (prehranskimi) in kalibracijskimi omejitvami (Heckelei in Britz, 2000). Z dodanimi kalibracijskimi omejitvami pridemo do rešitve samo v primeru, da je referenčni obrok skladen z omejitvami modela. Na prvi pogled gre za povsem trivialno trditev, vendar se le-ta lahko izkaže kot problematična, če z modelom analiziramo sestavo podobnih krmnih obrokov, katerih sestavine imajo zaradi najrazličnejših vzrokov povsem različne hranilne vrednosti.

S pomočjo dualnega programa dobimo senčne cene kalibracijskih omejitev. V drugem koraku (5 in 6) na podlagi senčnih, lastnih in tržnih cen izračunamo parametre stroškovne funkcije. S pomočjo teorije povprečnih stroškov izpeljemo α, ki predstavlja presečišče stroškovne funkcije in parameter β, ki predstavlja naklon stroškovne funkcije.

V zadnji fazi kalibriranja uporabimo izračunane parametre stroškovne funkcije. Namenska funkcija (7) se zaradi kvadriranja (x_i^2) spremeni v nelinearno, pri kateri zopet iščemo maksimum. Tako prilagojena in 'uravnotežena' namenska funkcija, ob upoštevanju prehranskih omejitev, nam brez kalibracijskih omejitev vrne sestavo referenčnega krmnega obroka. Na tako pripravljenem modelu lahko nato študiramo npr. vpliv sprememb cen in stroškov preteklega desetletnega obdobja. V našem primeru smo kot referenčni krmni obrok izbrali nekoliko prilagojen krmni obrok, predpostavljen v modelnih kalkulacijah (KIS, 2008).

Prehranske potrebe bikov pitancev

Seveda gre pri sestavljanju krmnih obrokov za številne dejavnike, ki vodijo kmeta pri njegovem odločanju. Poleg izbrane pasme, velikosti kmetijskega gospodarstva ter razmerja med ornimi in travnimi površinami, ki določajo potrebe po krmi ter razmerje med doma pridelano in kupljeno krmo, je pomembna tudi tehnologija pitanja. Za analizo smo izbrali tehnološke predpostavke analitične modelne kalkulacije (KIS, 2008). Predpostavili smo, da se pitanje začne pri telesni masi 120 kg in se konča pri telesni masi 550 kg. Povprečen dnevni prirast preko celotnega obdobja znaša 0,9 kg/dan, kar pomeni, da pitanje traja 478 krmnih dni.

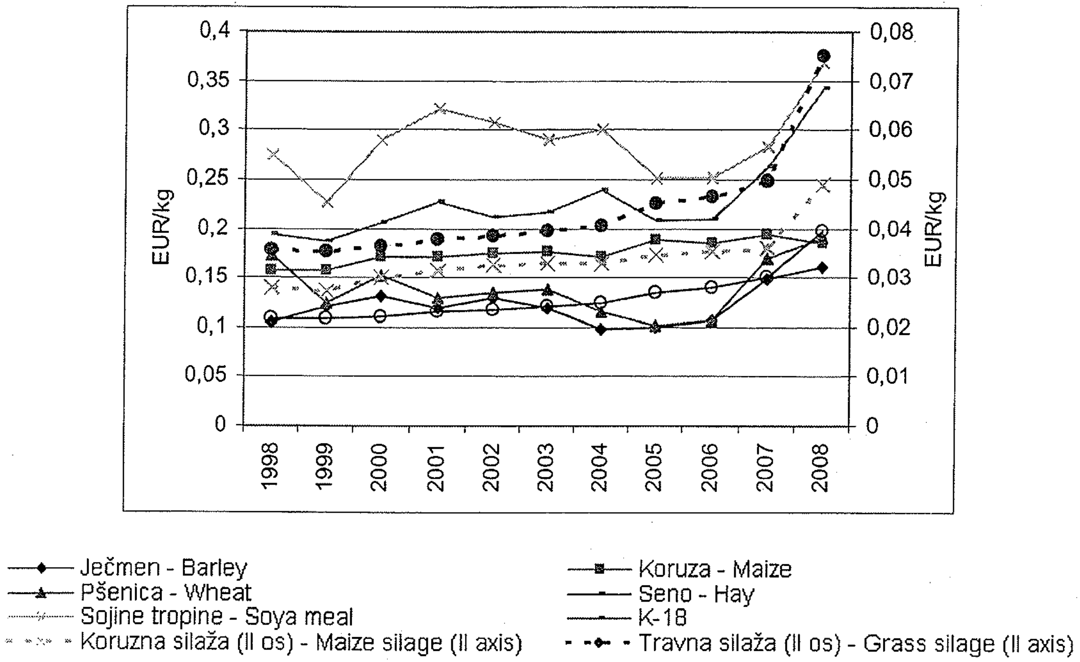
Ker se za potrebe modelnih kalkulacij uporablja starejši sistem škrobnih enot, smo prehranske potrebe pitancev ocenili s pomočjo simulacijskega modela za ocenjevanje prehranskih potreb prežvekovalcev, ki temelji na presnovni energiji. Simulacijski model je podrobneje opisan v Žgajnar in sod. (2007).

Kupljena in doma pridelana krma

Za analizo smo izbrali najpogostejši način pitanja v Sloveniji. Predpostavili smo, da kmetijsko gospodarstvo večji del krme pridela na lastnih zemljiščih, del močne krme pa dokupi na trgu po tržnih cenah. Ker voluminozne krme večinoma ni tržna dobrina, smo na podlagi izračunov modelnih kalkulacij ocenili skupne stroške pridelave posamezne krme in jih nadalje ovrednotili s polno lastno ceno (brez upoštevanja morebitnih subvencij). Za razliko od metode pokritja, kjer so zajeti zgolj spremenljivi stroški, modelne kalkulacije vključujejo vse stroške, ki so povezani s pridelavo, kamor prištevamo tudi stroške dela (Rednak, 1998). Ob tem je potrebno podariti, da smo upoštevali zgolj stroške, povezane s pridelavo glavnega pridelka oziroma pridelka, ki ga lahko vključimo v krmni obrok.

Pri vrednotenju krme po polni lastni ceni ima ekonomija obsega ključno vlogo. Zato je potrebno izpostaviti, da kalkulacije temeljijo na predpostavki, da je velikost parcel 1 ha in so od kmetijskega gospodarstva oddaljene 1 km. Serijo osnovnih podatkov med leti 1998 in 2008 smo pridobili na spletni strani Kmetijskega inštituta, kjer imajo objavljene t.i. zbirnike podatkov na letni ravni (KIS, 2008).

Prva dva modela (LP in WGP) lahko pri sestavljanju krmnega obroka izbirata med osmimi vrstami krme (slika 1). Na razpolago imata pet vrst močnih krmil (ječmen, koruza, pšenica, dopolnilna krmna mešanica K-18 in sojine tropine), ter tri vrste voluminozne krme (seno, koruzna silaža in travna silaža). Predpostavili smo, da rejci vsa močna krmila dokupijo po tržnih cenah. Na lastnih zemljiščih pa pridelajo seno, travno in koruzno silažo. Slednje lahko ovrednotimo po njihovi polni lastni ceni. Kot je razvidno s slike 1, se je v opazovanem obdobju vsa krma podražila.



Slika 1: Gibanje tržnih cen močne krme ter polnih lastnih cen doma pridelane voluminozne krme v obdobju 1998 - 2008

Figure 1: Changing market prices and total unit costs for feed and voluminous forage in the period 1998 - 2008

Izračunane polne lastne cene doma pridelane voluminozne krme so se vse od leta 1998 nenehno zviševale. S podrobnejšo analizo smo ugotovili, da je zviševanje cen voluminozne krme posledica predvsem vse dražjih strojnih storitev in vse višjih postavk domačega dela ter kapitala. Poleg tega so se v opazovanem obdobju tudi mineralna gnojila nenehno dražila, kar je bilo še posebej izrazito v zadnjih dveh letih. V letu 2008 so se denimo cene mineralnih gnojil zvišale skoraj za trikrat. Slednje je tudi ključni razlog, da so se lastne cene pridelkov v zadnjem letu tako povečale. Slika bi bila nekoliko drugačna, če bi pretežen del rastlinskih hranil rejci zagotovili z gnojem domačih živali. S slike 1 je razvidno, da se je cena travne silaže v primerjavi s koruzno silažo relativno hitreje zviševala. Izrazit razkorak se kaže od leta 2002 dalje. Na prvi pogled nelogično dejstvo je moč pojasniti s količino pridelka na enako površino zemljišča. Pridelek travne silaže je bistveno manjši v primerjavi s sicer že tako ali tako cenejšo koruzno silažo, zato so stroški pridelave travne silaže na enoto pridelka večji.

Nihanja so opazna tudi pri kupljeni močni krmi. Dvig cen je nedvomno posledica kompleksnih pojavov in vplivov, ki pa jih ni mogoče enoznačno opredeliti. S slike 1 je razvidno, da so energijska krmila (koruza, pšenica in ječmen) v primerjavi s pretežno beljakovinsko krmo (sojine tropine) in sestavljenim močnim krmilom K-18 bistveno cenejša. Koruzno zrnje je v vsem opazovanem obdobju dražje od pšenice in ječmena, ki se izraziteje podražita šele v zadnjih treh letih.

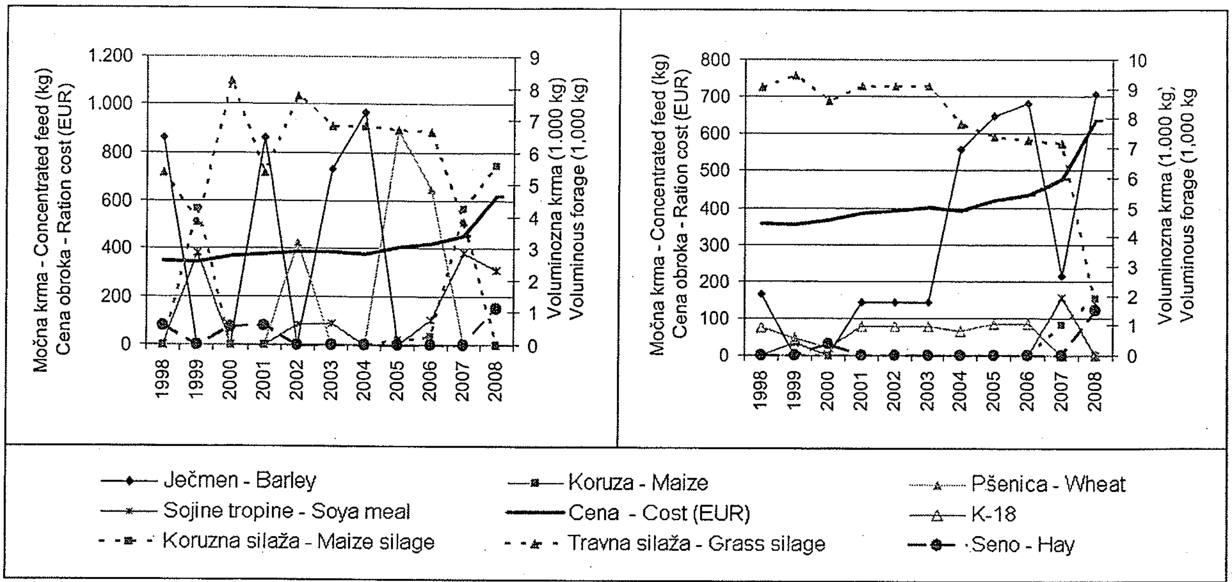
Za pokrivanje potreb po rudninskih snoveh so v nabor krmil vključene tudi štiri rudninsko vitaminske mešanice. Sprememb njihovih cen v danem obdobju ne prikazujemo, saj zaradi manjše količinske zastopanosti v obroku ne vplivajo na našo analizo.

Pri optimiranju sestave krmnega obroka sta, poleg ekonomskega vidika, ključnega pomena hranilna vrednost in kakovost krme. Obe sta odvisni od številnih dejavnikov kot so kakovost tal, klimatski dejavniki, količine padavin, tehnologije pridelave in tehnologije spravila. Iz tega sledi, da lahko kakovost krme med leti močno niha, kar lahko povzroči, da obroki s povsem enako sestavo ne pokrijejo vedno vseh potreb živali po hranljivih snoveh. V naši analizi smo ta vidik zanemarili; v izračunu smo upoštevali nekoliko nadpovprečno hranilno vrednost krme, ki je bila enaka v celotnem obdobju opazovanja.

REZULTATI IN RAZPRAVA

Rezultate modelov prikazujemo v enakem vrstnem redu, kot so opisani uporabljeni pristopi. Najprej pokažemo, kako bi se sestava obroka spreminjala, če bi bil rejec povsem prilagodljiv in bi bil njegov edini cilj minimiranje stroškov (rezultati LP). Sledijo krmni obroki, ki so sestavljeni s pomočjo tehtanega ciljnega programiranja. Nadaljujemo s predstavitvijo rezultatov post-optimalne analize in njihovega pomena. V zadnjem delu se osredotočimo na simulirane krmne obroke s pomočjo PMP modela. Vsi grafikoni, ki prikazujejo skupne stroške in strukturo krmnih obrokov, se nanašajo na celotno obdobje pitanja.

V prvi model smo vključili 12 vrst krme, iz katerih smo sestavili najcenejši možni krmni obrok. S slike 2 je razvidno, da se sestava tega krmnega obroka med leti močno spreminja. Značilnost LP je namreč prekinjen (nezvezen) odziv na spremenjene zunanje razmere – v našem primeru tržne cene oziroma izračunane polne lastne cene. Posledično se dobljena rešitev izrazito spreminja med leti in kar je bolj problematično, iz dobljenih rezultatov se ne da izluščiti neke splošne zakonitosti, kaj se je v opazovanem obdobju dogajalo s sestavo krmnega obroka in napovedati, kakšna bodo gibanja v prihodnosti. To dejstvo je še zlasti izrazito pri vključevanju energijskih močnih krmil v obrok.

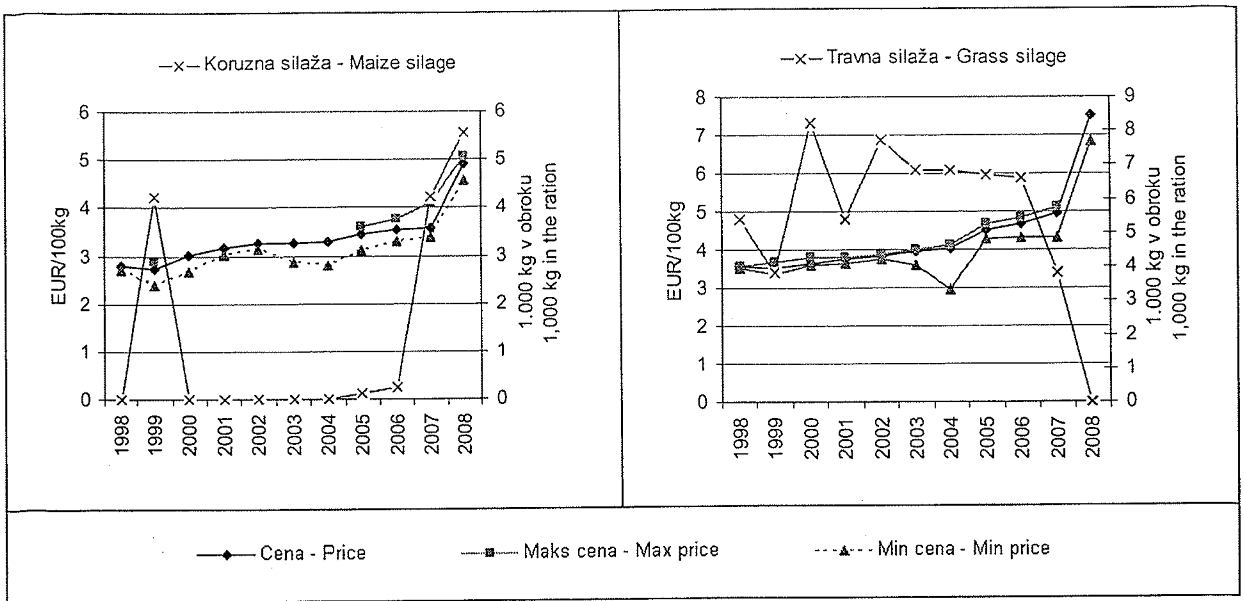


Slika 2: Krmni obroki v obdobju 1998 do 2008, sestavljeni s pomočjo linearnega in tehtanega ciljnega programa
Figure 2: Rations for the period 1998 to 2008, calculated with linear and weighted goal program

S slike 2 je razvidno, da manjkajoče potrebe po energiji z izjemo leta 1999 in zadnjih dveh let, kjer v krmni obrok vstopa koruzna silaža, pokrijemo s pšenico in ječmenom, ki se v krmnem obroku linearnega modela pojavljata kot alternativi. Predvsem v zadnjem obdobju se zaradi vse dražje doma pridelane travne silaže količina sojinih tropin, kot vira beljakovin, v obroku povečuje. Zviševanje cen sojinih tropin je vse od leta 2005 dalje na enoto beljakovin manjše kot pri travni silaži. Drago koruzno zrnje ni vključeno v rešitev. Svoj delež k temu doprinese tudi povečana količina koruzne silaže v krmnem obroku. Kljub rahlemu povečanju količine koruzne silaže v obrokih, postaja zagotavljanje ustrezne strukture obroka (strukturna vlaknina iz voluminozne krme) ključen problem. Na to je pokazala tudi dodatna analiza senčnih cen, ki so pri omejitvi zagotavljanja najmanjšega deleža strukturne vlaknine v obroku najvišje. Nedvomno je to posledica dragega in kakovostnega sena. Izračunane senčne cene bi bile tako bistveno drugačne, če bi imeli v naboru voluminozne krme cenejše seno slabše hranilne vrednosti.

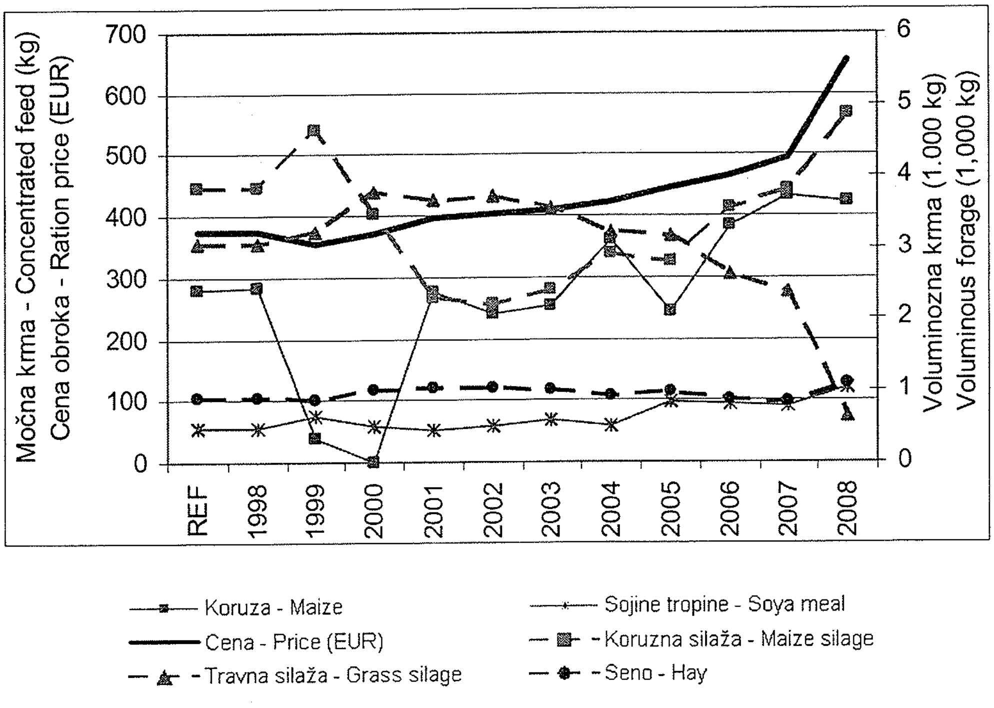
Do nekoliko drugačnih zaključkov pridemo pri rešitvi WGP, ki po definiciji išče s prehranskega vidika bolj uravnotežen krmni obrok. Ker ima sama cena nekoliko manjši vpliv, je pričakovano, da je obrok v primerjavi z obrokom linearnega modela nekoliko dražji. Razvidno je, da se med leti sestava obroka spreminja predvsem na račun zmanjševanja količine travne silaže in povečevanja količine ječmena v obroku. To je tudi edini obrok, ki vključuje relativno drago krmno mešanico K-18, kar je nedvomno posledica manjšega pomena stroška krmnega obroka pri ciljnem programiranju. Zanimivo je, da koruzna silaža z izjemo zadnjih dveh let ni zastopana v nobeni rešitvi WGP.

V vsem opazovanem obdobju je pri rezultatih obeh metod opazen izrazit trend podražitve krmnega obroka. S pomočjo dodatnih izračunov smo ugotovili, da se pri linearnem programu med leti stroški vsebovane močne krme praktično ne zvišujejo. V desetletnem obdobju vseskozi ostajajo na ravni 100 EUR, z izjemo zadnjih dveh let, ko se zvišajo za slabih 20 EUR na pitanca. To pomeni, da dvig cen vodi do vse večjega deleža voluminozne krme v skupnem strošku krmnega obroka. Precej drugačne zaključke lahko potegnemo iz rezultatov WGP. Do leta 2003 so namreč stroški močnih krmil predstavljali okrog 10 %, po tem letu pa zelo hitro narastejo na nekaj manj kot 20 % celotnih stroškov krmnega obroka.



Slika 3: Stabilnost dobljenih rešitev linearnega programa:primer koruzne in travne silaže
Figure 3: Stability of obtained linear program solutions: maize and grass silage

Na sliki 3 prikazujemo izračunane meje, znotraj katerih se lahko gibljejo lastne cene koruzne in travne silaže, ne da bi ob tem prišlo do sprememb v sestavi krmnega obroka. Prikazujemo zgolj rezultate za obe silaži, ki sta se izkazali za ključni pri sestavi krmnega obroka. S slike 3 je razvidno, da se cena travne silaže praktično ves čas giblje na zgornji meji. V danih razmerah to pomeni, da bi se količina v obroku zmanjšala takoj, ko bi cena narasla. Nasprotno lahko ugotovimo pri koruzni silaži, kjer je cena, z izjemo leta 1999 in zadnjih štirih let, ves čas nad najvišjo dovoljeno ceno in zato koruzna silaža ni vključena v rešitev. Kljub izrazitemu dvigu lastne cene koruzne silaže v zadnjih dveh letih pa bi le-ta lahko še narasla, ne da bi to vplivalo na dobljeno rešitev. Glede na aktualna cenovna razmerja je bilo koruzno zrnje v primerjavi z ostalo krmo, dostopno na trgu, predrago, zato ni bilo zajeto v rešitvi.



Slika 4: Simuliranje sprememb v sestavi krmnega obroka s pomočjo pozitivne analize
Figure 4: Simulation of ration structure changes with positive analysis

S pomočjo tretjega modela (PMP), ki je bil razvit za potrebe te analize, smo simulirali, kako bi se rejec glede na svoje preference odzival na 'zunanje' spremembe. Kot referenčno situacijo smo izbrali cenovno – stroškovna razmerja iz leta 1998. Predpostavili smo, da je t.i. referenčni krmni obrok (REF) nekoliko prilagojen krmni obrok iz modelnih kalkulacij. Na sliki 4 prikazujemo, kako bi sprememba cen po posameznih letih vplivala na sestavo krmnega obroka 'racionalnega' rejca. Referenčni obrok za celotno obdobje pitanja naj bi tako vključeval nekaj manj kot štiri tone koruzne silaže, dobre tri tone travne silaže, nekaj manj kot 900 kg sena, 280 kg koruznega zrnja in dobrih petdeset kilogramov sojinih.

S slike 4 je razvidno, da vse dražja travna silaža počasi izgublja pomen v krmnem obroku. Hkrati se delež koruzne silaže v obroku povečuje vse od leta 2002 naprej. V tem letu se je namreč travna silaža v primerjavi s koruzno silažo začela močneje dražiti. Simulacija je pokazala tudi, da je z izjemo leta 2000 koruzno zrnje vključeno v krmni obrok, kar je glede na rezultate prejšnjih modelov dokaj neracionalno. Na tem preprostem primeru se izkaže značilnost (pomanjkljivost) PMP metode, saj lahko kalibriramo zgolj tiste aktivnosti (v našem modelu vrste krme), ki so vključene že v referenčni (izhodiščni) rešitvi, ne pa tudi tistih, ki so prav tako na razpolago in jih kmet v referenčni situaciji zaradi takšnih ali drugačnih razlogov ni uporabil. Z drugimi besedami to pomeni, da je lahko pri klasičnem PMP pristopu v rešitev zajeta zgolj tista krma, ki jo je vključevala referenčna (REF) situacija.

Pri kalibriranju modela je bila senčna cena kalibracijske omejitve koruznega zrnja enaka nič. Posledično je tudi parameter β enak nič, kar pomeni, da je 'odzivanje' rejca pri vključevanju koruznega zrnja v obrok ostalo linearno. Heckelei (2002) takšne aktivnosti imenuje mejne aktivnosti (marginal activities). Značilnost slednjih je, da so omejene s strani 'klasičnih' omejitev in ne zgolj s strani dodatnih kalibracijskih omejitev, kar je značilnost bolj zaželenih aktivnosti. Heckelei (2002) opozarja na t.i. fenomen substitucije, kar se v našem primeru zaradi podražitve bolj zaželenih aktivnosti odraža v večjem vključevanju koruznega zrnja v obroku.

SKLEPI

Na podlagi dobljenih rezultatov lahko zaključimo, da se je strošek krmnega obroka v zadnjih desetih letih tudi pri optimizaciji nenehno povečeval. S pomočjo normativnih modelov smo ugotovili, da bi teoretično bolj prilagodljivi rejci s pogostejšim optimiranjem sicer lahko zniževali stroške krmnega obroka, ki pa bi v zadnjih desetih letih še vedno kazali izrazit trend rasti. Bistven problem pri normativni analizi, zlasti LP, se je izkazal zaradi značilnega prekinjenega (nezveznega) odziva na spremenjene tržne cene oziroma izračunane polne lastne cene. Posledično se dobljena rešitev močno spreminja med leti in, kar je še bolj problematično, iz dobljenih rezultatov se ne da izluščiti nekega splošnega trenda, v katero smer se je spreminjala sestava krmnega obroka v obravnavanem obdobju. Prav tako nam takšen normativen matematičen model ne omogoča, da bi izračunali dejansko - referenčno stanje. To se izkaže kot problem v primeru, če na določenem kmetijskem gospodarstvu rejec krmi obrok, ki z ekonomskega vidika ni racionalen, je pa zaradi določenih okoliščin edino možen (npr. razmerje med njivskimi in travnatimi površinami). V takšnem primeru ne moremo opazovati, kako sprememba cen krme in krmil vpliva na sestavo krmnega obroka, saj z modelom kljub dodatnim omejitvam ne moremo simulirati realnega stanja.

S pomočjo PMP modela smo simulirali, kako bi se povprečen rejec, glede na svoje preference, odzival na zunanje spremembe. Dobljeni rezultati kažejo, da se je sestava krmnega obroka v zadnjih desetih letih nagnila v prid koruzne silaže na račun travne silaže. Vsekakor dobljenih rezultatov ne gre posploševati, saj je struktura lastnih cen v veliki meri odvisna od stalnih stroškov, ki pa se med posameznimi kmetijskimi gospodarstvi močno razlikujejo.

Posledično bi bila lahko situacija na posameznem kmetijskem gospodarstvu precej drugačna, v največji meri pa odvisna od ekonomske učinkovitosti gospodarstva.

V praksi seveda nismo in tudi ne bomo zasledili tako izrazitih trendov, zlasti ne tako izrazitega zmanjšanja količine travne silaže v obroku. Realnejše rezultate bi dobili s t.i. kmetijskim modelom, ki bi kot omejitev vključeval tudi površine obdelovalnih zemljišč, hkrati pa bi zajel tudi druge omejitve, ki so prav tako pomembne in posredno vplivajo na vodenje kmetijskega gospodarstva. Značilnost oziroma predpostavka modelov, ki smo jih uporabili pri analizi, je, da ne upoštevajo razmerja zemljišč (travniki : njive), kot tudi ne, da le-ta ne smejo ostati neizkoriščena in ostalih omejitev, ki jih SKP nalaga kmetom. Dobljene rezultate zato lahko tolmačimo tudi na nekoliko drugačen način. Dobljeni trendi kažejo na nujnost iskanja možnosti cenejše pridelave krme, bodisi z izboljševanjem tehnologije oziroma kjer je možno, z ekonomijo obsega. Iz dobljenih rezultatov bi tako lahko zaključili, da bo predvsem pri spravilu travne silaže potrebno posvetiti več pozornosti zniževanju stroškov.

SUMMARY

Due to changing political and economic environment, beef fattening has recently become one of the most sensible sectors within EU agriculture. Its poor economic position is mainly caused by the change of the common agricultural policy (CAP). Strongly protectionist oriented policy from the past has changed fundamentally in the last few years. Starting with MacSharry reform in 1992 that was continued with Agenda 2000 and the reform in 2003, implemented in Slovenia in 2007, CAP is abandoning previous market-price policy instruments in favour of new decoupling concept. It is expected that such approach should yield more market oriented farmers. But in the beef sector this is so far more reflecting in worsening economic position. Production costs are much higher than price achieved at the global market. The main cost in fattening, beside calve purchase, goes to ration costs. In Slovene circumstances it presents up to 55 % of total cost or around 70 % of variable cost. This is especially important, since feed and fodder price trend is positive and in last few years more and more steep. This is due to additional demand for grains caused by bio-energy production, decreased grains production (draughts, floods etc.) in strategic regions in the world as well as energy price rise (fertilizers and gasoline).

In this study we have analysed how optimal beef rations have been changing in the last decade due to changes in feed price and estimated fodder total costs. Model calculations, prepared by Slovene Agricultural Institute (KIS, 2008) have been used for estimation of total costs for home produced forage.

Three mathematical programming methods based on constraint optimization have been applied. They tend to solve basic economic problem – making the best use of limited resources, which is the basic concept of neoclassical economic theory (Buysse et al, 2007). Constrained optimisation models could be split into normative and positive ones.

The normative analyses have been done with already developed tool - decision support system (DSS) for beef ration formulation (Žgajnar and Kavčič, 2008). According to the purpose of this study it has been slightly adapted in the sense of total cost approach and fattening periods, which have been jointed into one period. Both sub-models could formulate rations from five purchased feed and three home produced voluminous forages. With the common LP approach (the first sub-model) the least cost ration has been formulated as well as post optimal analyses have been performed to estimate the stability of obtained solutions. The second sub-model, based on weighted goal programming (WGP), served for calculation, how farmer that pays more attention to the quality and not mainly on economics would have formulated the ration. To estimate how an average farmer (we took the presumptions of the model calculation (KIS, 2008)) would have react on external – feed and fodder price changes, an model based on positive

mathematical programming (PMP) approach has been developed. Calibration process is done by the most widely applied approach, proposed by Howitt (1995).

All three models have shown that ration costs have significantly increased in the last decade. With optimization process it was possible to reduce costs, more efficiently in the case that ration costs was, besides satisfying nutrition constraints, the most important objective of the farmer (LP). On the basis of calibrated model (PMP), we have simulated how an average farmer would have change the manner of ration formulation. The main drawback of this method is, that model can 'play' only with the feeds that are included in the reference ration (REF). It comes from the analysis that the main problem is expensive grass silage that has explicit negative trend in ration structure and vice versa holds for maize silage. Of course this is only applicable when there are no constraints on tillage area, policy rules etc., what is assumed in our study. Obtained results could be therefore interpreted in the way that for improving economic position of the fattening, home produced fodder costs have to be reduced, either with improved cost – efficient technology or economics of scale.

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OPTIMIZATION OF BULLS FATTENING RATION APPLYING MATHEMATICAL DETERMINISTIC PROGRAMMING APPROACH

J. ZGAJNAR and S. KAVCIC
University of Ljubljana, Biotehnical Fac., Dept. of Animal Science, Groblje 3, SI-1230 Domzale, Slovenia

Abstract

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The more specialized beef farms demand the more precise management to achieve economically justified outcome. Undergoing CAP reform and market liberalisation are just some of numerous factors that are going to have significant impact especially on expenditures rise in the beef sector. Forage variable cost already range between 40 % and 70 % of total variable cost of bulls fattening in Slovenia. Ration formulation is therefore becoming fundamental lever of beef farms management. To support beef farmers we present a user friendly tool developed in Excel framework that utilizes mathematical deterministic programming techniques. Paper illustrates the supplementation of linear program by weighted goal program resulting in more efficient beef ration formulation. User can decide either to minimize forage costs, to achieve more balanced ration or to implement own weights about importance of both, always based on feed at his/her disposal. In this way the tool developed is applicable for practical decision making on beef farms, enabling cost-effective and nutrient-balanced beef production.

Key words: linear programming, weighted goal programming, ration optimization, beef farming, beef economics

Abbreviations: a_{ij} - The quantity of the i-th nutrient in one unit of j-th feed; b_i - The amount of the i-th resource available – right hand side (RHS); C - Objective function (LP); CF - Crude fibre; c_j - j-th feed cost; d_i+ - Positive deviation variables including over achievement of the i-th goal; d_i- - Negative deviation variables including under achievement of the i-th goal; DM - Dry matter; g_i - Expected daily requirement of the i-th nutrient (goal); LP - Linear program; MCDM - Multi criteria decision making; ME - Metabolic energy (expressed in MJ - mega Joule); MP - Metabolisable proteins; MVM - Mineral-vitamin mixture; WGP I- Weighted goal programming, the first scenario; WGP II - Weighted goal programming, the second scenario; WGP - Weighted goal program; w_i - Weight expressing the relative importance of achieving of the i-th goal; X_j - The level of j-th feed; Z - Objective function (WGP)

Introduction

Process of further commercialisation of already specialized agricultural holdings is demanded through numerous factors. Progressive abolition of initial CAP scheme and increasing environmental and other public demands are leading to rapid market fluctuations. These facts already have and are going to have also in

e-mail: jaka.zgajnar@bfro.uni-lj.si

the future significant impact on beef farming. Besides direct consequences on beef market there are indirect influences that are going to provoke an increasing economic challenge for beef farmers. One of them is undoubtedly (further) reform of the CAP in relation to growing importance of renewable energy that is going to happen. As a result energy crop production has come to offer an alternative for agricultural enterprises as it opens new income sources for arable farmers besides food production. Simultaneously additional demand is going to lead to higher prices and better economic position of arable farmers is expected (Zeller and Hдring, 2007). This non-food production and positive effect on prices is definitely going to cause significant issue for livestock sector, where cereals and some other crops are indispensable inputs.

Slovene gross margin calculations (Jeric, 2001) show that feed expenses in beef production range between 40 and 70 % of total variable costs. Formulation of balanced and as cheap as possible daily ration for animals is therefore becoming the fundamental lever for improving economic situation. It includes both choosing the most suitable and cheapest feed that is at disposal (on the farm and/or market) in that moment as in the meaning of its efficient use. The latter means that ration should be balanced not only on the level of energy, proteins and fibre but also on the level of macro and micro minerals and vitamins. Finally this results in animals' health, consequentially also in production and profitability.

Nutritionist doctrine assures that animals use feed most efficient when the nutrients in the daily rations match their daily requirements. Such ration is termed as 'balanced ration'. As already stated there are numerous factors that should be taken into consideration to prepare balanced rations. In order to help breeders to deal with these challenges many tools have been developed. In the literature we can find numerous examples utilising mathematical techniques for solving nutrition management problems. The most frequent technique used is deterministic linear programming. It is a classical approach to formulate animal diets and also appropriate tool to optimize human nutrition (Darmon et al., 2002). When focusing only on livestock diets, one can find out that the most frequent manner of utilizing linear programming technique is least-cost ration formulation. For the first time it has been used by Waugh (1951). He optimized livestock ration in economic terms with classical linear program. In the literature one can find this technique also to assess the value of forages in providing the energy requirements of growing animals (Magowan and O'Callaghan, 1986), to maximize intake of energy, nitrogen, phosphorus or sodium, or to minimize feeding time of free-living beavers (Nolet et al., 1995).

Common to all minimisation or maximisation problems is single objective function as the basic concept of linear programming. It means that one try to get the optimal solution in minimizing or maximizing desired objective within set of constraints imposed. From this point of view linear programming could be deficient method for ration formulation (Rehman and Romero, 1984; 1987). In many real life situations like livestock ration formulation, decision maker does not search for optimal solution on the basis of a single objective (usually cost minimization of the diet), but rather on the basis of several different objectives (Lara and Romero, 1994). Rehman and Romero (1984) mentioned as the main weakness of utilizing the linear program for least-cost ration formulation in exclusive reliance on cost function as the only and the most important decision criteria. After all, this is very rigid assumption. Ration formulation is namely much more complex process and economic issue is only one of many objectives on one hand and constraints on the other.

Rehman and Romero (1984) are also mentioning mathematical rigidity of constraints, which usually results in fact that set of equations does not have a feasible solution. This means that no constraints' (e.g. given nutrition requirements) violence is allowed at all, irrespective of deviation level. On the other hand there are no upper limits (minimization case) or lower limits (maximization case). The latter could reflect in rise of prime-cost or, what is lately becoming even more important, increase pollution with surplus elements due to unbalanced ration.

Limitation problem could easily be solved by adding additional constraints, but this could rapidly lead to over-constrained and complex model that has no feasible solution (Lara, 1993). Of course this rigidity could not yield an applicable solution. In other words relatively small deviations in right hand side (RHS) would not seriously affect animal welfare, but would result in a feasible solution (Lara and Romero, 1994).

The most appropriate method that partly overcomes listed problems of linear program is weighed goal programming (WGP). It is a pragmatic and flexible methodology for resolving multiple criteria decision making (MCDM) problems what ration formulation definitely is. Tamiz et al. (1998) are pointing out that goal programming has been and still is the most widely used MCDM technique. It is an appropriate tool to deal with nutrition management problems and has been introduced by Rehman and Romero (1984). Based on linear programming it is special form of it (Zadnik Stirn, 2001) and could be therefore also solved by simplex algorithm (Rehman and Romero, 1993).

Important part in formulating WGP is to set targets and their values. This is actually domain of nutritionists and experts from this field of science. Basic concept of WGP formulation is to set weights to belonging goals. One of many possibilities could be sensitivity analysis, where only binding goals should be considered. Rehman and Romero (1993) strongly recommend its application, especially when one is not confident about priorities of the goals. Quality of obtained results is strongly dependent on selection of preferential weights. To reduce bias of obtained result sometimes also additional technique to define weights should be used (Gass, 1987).

In most cases obtained solution is compromise between contradictory goals. Compromise is enabled with deviation variables. WGP in comparison with LP therefore allows deviations, but they are not desired. They are measured using positive and negative deviation variables that are defined for each goal separately and present over- or under-achievement of the goal. Negative deviation variables are included in the objective function for goals that are of type 'more is better' and positive deviations variables are included in the objective function for goals of type 'less is better'. The relative importance of each deviation variable is determined by belonging weights. The objective function is defined as weighted sum of the deviations variables. Hence, the objective function in WGP model minimizes the undesirable deviations from the target goal levels and does not minimize or maximize goals themselves (Ferguson et al., 2006).

Observed goals are measured in different units of measurement and this is why deviation variables could not simply be summed up and taken as absolute values. Therefore all objective function coefficients have to be transformed with mathematical process of normalization (equation 1) into the same units of measurement.

$$w_i\left(\frac{d_i^+}{g_i}\right)+w_i\left(\frac{d_i^-}{g_i}\right) \qquad (1)$$

Material and Methods

Optimization tool for beef ration formulation has been developed in Microsoft Excel framework. In its basic version it includes a macro called solver that in the case of linearity utilizes simplex algorithm. Our aim is to describe how combination of LP and WGP could be used to prepare user friendly tool for 'optimal' ration formulation, illustrated by beef production example. It is developed in the shape of an open spreadsheet model. For any analysed case it could be rapidly updated with appropriate input data. Also the set of goals and their priorities could be changed. Initial

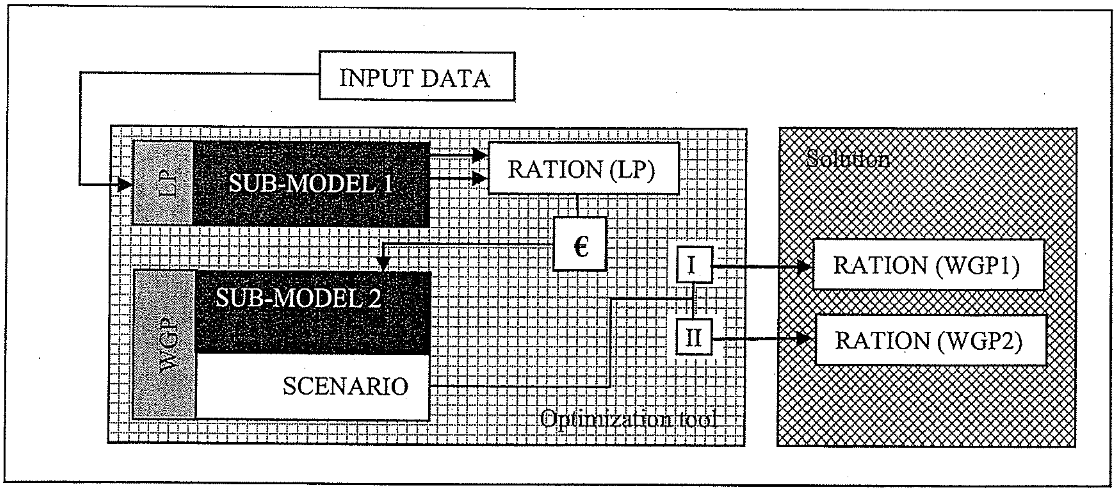

Fig. 1. Scheme of developed tool for beef ration formulation

model version is linked with another already developed tool for estimation of ruminants' nutritional requirements (Zgajnar et al., 2007) that is the main source of 'technological' input data.

In the article presented tool for beef ration formulation is based on two sub models (Figure 1). The first sub-model is actually an example of least-cost ration formulation. On the basis of the most important non-competitive constraints, it searches for the roughly balanced ration at the least possible cost. As already pointed out, LP has some drawbacks that could reflect in complex practical situation as useless solution. Therefore the second sub-model, supported by WGP, should formulate especially from nutrition viewpoint more reliable ration. One of the goals in the second sub-model is also to draw close to obtained ration cost from the first sub-model. Combination of both should yield more nutritionally balanced ration that is in terms of costs comparable with the obtained solution form LP.

The first sub-model could be mathematically formulated as shown in equations (2) to (4). It mostly relays on economic (cost) function (C) and satisfies only the most important nutrition requirements coefficients (b_i), known also as right hand side (RHS). From practical viewpoint of presented approach, LP might neglects ratios between the four observed mineral elements if they in real case situation lead into an over-constrained model that has no feasible solution.

First (LP) sub-model:

Obtained LP solution should meet all nutrition requirements imposed at lowest possible cost (c_j). For all purchased feed we consider market prices and for home produced feed marginal costs. These two fac-

$$\min C = \sum_{j=1}^{n} c_j * X_j \quad \text{such that} \tag{2}$$

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \quad \text{for all } i = 1 \text{ to m, and} \tag{3}$$

$$X_j \geq 0 \tag{4}$$

tors are mostly dependent on markets situation including CAP measures in place and of course also on the technology applied. Technological coefficients (a_{ij}) present the quantities of the ith nutrient in one unit of the jth feed.

Second (WGP) sub-model:

$$\min Z = \sum_{i=1}^{k} w_i \frac{d_i^- + d_i^+}{g_i} \quad \text{such that} \tag{5}$$

$$\sum_{j=1}^{n} a_{ij}X_j = g_i \quad \text{for all } i = 1 \text{ to r and } g_i = 0 \qquad (6)$$

$$\sum_{j=1}^{n} a_{ij}X_j + d_i^- + d_i^- = g_i \quad \text{for all } i = 1 \text{ to r and } g_i \neq 0 \qquad (7a)$$

$$\sum_{j=1}^{n} c_jX_j + d_i^- + d_i^- = C \quad \text{for all } i = 1 \text{ to r} \qquad (7b)$$

$$\sum_{j=1}^{n} a_{ij}X_j \leq b_i \quad \text{for all } i = 1 \text{ to m} \qquad (8)$$

$$d_i^+, d_i^-, X_j \geq 0 \qquad (9)$$

The meanings of the first and the second sub-model notations:

Z and C - objective function;

a_{ij} - the quantity of the *i*th nutrient in one unit of *j*th feed;

X_j - the level of *j*th feed;

c_j *j*th feed cost;

b_i - the amount of the *i*th resource available - right hand side (RHS);

g_i - expected daily requirement of the *i*th nutrient (goal);

w_i - weight expressing the relative importance of achieving the *i*th goal;

d_i^+, d_i^- - positive and negative deviation variables including over- and under achievement of the *i*th goal

WGP sub-model could be formulated in mathematical terms as shown in equations (5) to (9). The objective function is defined as weighted sum of undesired deviation variables from observed goals (5) and is subject of minimization. The relative importance of each goal is represented by weights (w) associated with the corresponding positive or negative deviations. Because of the normalization process, only goals that have nonzero target values (7a, 7b) could be relaxed with positive and negative deviations. In other case (6) we would face forbidden division by zero.

The second sub-model is directly connected with the first one through cost function (7b). Obtained target value (C) from the first sub-model enters in the second sub-model as goal that should be met as close as possible. All the rest constraints that do not have defined target value or do not have priority attribute are considered in equation (8). One of the main assumptions of the linear programming is also non-negativity that is considered in equation (4) for the first sub-model and in equation (9) for the second one.

Input data

The primal aim of developed tool is to assist breeders in formulating a ration that is both from nutritional and from economic viewpoint more efficient. It could be used also to assess the variable cost of feed used.

In this paper we are going to present a hypothetical case. We presumed that beef fattening starts at 200 kg of live weight and stops at 650 kg. This fattening horizon has been divided into three periods with different average daily weight gains (Table 1). Nutritional requirements are presented in absolute values (Table 2) and have been assessed with the spreadsheet model for ruminants' nutritional requirements estimation (Zgajnar et al., 2007). It calculates requirements for metabolic energy (ME), metabolisable proteins (MP), dry matter consumption (DM), mineral elements (Ca, P, K, Na and Mg) and the minimal and maximal crude fibre (CF) for any breeding period investigated.

Table 1

Assumptions concerning growth pattern for beef cattle fattening

Indices	Fattening period		
	First	Second	Third
Average daily weight gain, g/day	900	1100	1000
Starting live weight, kg	200	350	500
Finishing live weight, kg	350	500	650
Fattening duration, day	167	136	150

Table 2
Nutrition requirements divided into three breeding periods, presented as constraints (LP) and goals (WGP) with belonging weights

Indices		Fattening period						Weights within scenario	
		First		Second		Third			
		LP	WGP	LP	WGP	LP	WGP	S I	S II
ME	(MJ)	>9.881	9 881	>11.003	11 003	>14.085	14 085	70	70
MP	(g)	>71.114	71 114	>71.335	71 335	>82.950	82 950	100	100
DM	(kg)	<1.036	1 036	<1.310	1 310	<1.467	1 468	33	33
CF min	(kg)	>186	>186	>236	>236	>264	>264		
CF max	(kg)	<269	<269	<341	<341	<381	<381		
Price	(eurocent)		*C1*		*C2*		*C3*	1	100
Ca	(g)	>6.460	6 460	>6.582	6 582	>7.800	7 800	5	5
P	(g)	>3.735	3 735	>4.297	4 297	>4.950	4 950	5	5
Na	(g)	>836	836	>961	961	>1.275	1 275	5	5
Mg	(g)	>1.171	>1.171	>1.441	>1.441	>1.800	>1.800		
K	(g)	>9.320	>9.320	>11.791	>11.791	>13.208	>13.208		
Ca:P	(%)	(1.5-2):1		(1.5-2):1		(1.5-2):1			
K:Na	(%)	(5.5-10):1		(5.5-10):1		(5.5-10):1			
Max hay	(kg/day)	2		2		2			
Min grass silage	(kg/day)	5		5		5			

The most important constraints for all three fattening periods are presented in Table 2. Basic set of constraints in both sub-models (LP and WGP) is more or less the same. Constraints presented in Table 2 differ only in mathematical sign when they are transformed into goals. The first sub-model (LP) claims only satisfaction of minimum or maximum constraints. As stated earlier this might lead into unrealistic solution. Linear sub-model is therefore included into the tool foremost to give rough estimate of the lowest possible cost for the animal diet that could be formulated with disposable feeds.

In the process of ration formulation one should also consider other 'non-nutrition' constraints. For example this could be quantity of feed that must or might be included into the diet. In our hypothetical case study we assume quite frequent example that might be met on Slovene beef farms. Because of our climate characteristics, the first grass mowing is gathered in hay and all the rest are gathered in grass silage. This is why both models must take into consideration maximal constraint of 2 kg hay per day and at least 5 kg of grass silage per day (Table 2).

Initial version of presented WGP model includes seven goals. Importance of each goal is defined with weights ranging between 0 and 100. As the most important goal in our case is satisfaction of protein requirements. We vary importance of 'cost goal' that manifests in two scenarios (Table 2). In the first scenario economics has rather low importance, while in the second scenario it has the highest possible weight. Satisfaction of energy requirement has in both scenarios the same weight. Much lower weight is foreseen for the dry matter intake that presents consumption capacity. At first glance it seems that all three mineral goals (Ca, P and Na) are, due to low weights, almost neglected. However this is not true. Developed model includes several safety nets that prevent mineral deficits as also their toxic concentrations in the ration. Nutritionists' doctrine says that it is more important to satisfy ratios between Ca and P and also between K and Na than to meet the estimated mineral requirements.

In analyzed hypothetical case we assumed that both sub-models might choose between six different feed and four different mineral-vitamin components (Table 3). Described feed characteristics are mostly dependent on soil structure, fertilization management and intensity of production.

We assumed that hay, grass silage and maize silage are grown on the farm. Since these forages are usually not tradable, we estimate variable cost of their production. Fixed costs were not considered at all. All the rest forage on disposal could be purchased at market prices (Table 3).

Results

Presented tool for nutrition management is built as an open system, which means that any beef case could be analysed. A hypothetical case has been chosen to test developed approach. Fattening time has been divided into three periods with different daily weight gains (0.9 kg, 1.1 kg and 1.0 kg). The first period starts at 200 kg body weight and than in each period bull gains 150 kg on weight. Fattening stops at 650 kg body weight.

Formulated rations for all three breeding periods are presented in Table 4. In the first period there is significant difference between formulated rations. Quantity of hay is the same in all three rations and achieves the highest allowed quantity (2 kg/day). Grain maize and rape seed cakes are included only in the second ration (WGP I) where the price is not of so high importance. From nutrition viewpoint this ration is the most suitable what manifests also in the lowest total deviation from nutrition requirements. The latest has been observed as one of those parameters that measures the 'quality' of obtained results. Total deviation has been in WGP I solution almost two times lower than in LP solution and 1.3 times lower than in WGP II solution where priority of cost goal is the same as satisfaction of protein target value. The third solution is from nutrition viewpoint still satisfactory. It misses protein requirements for one percent and deviation from mineral requirements are slightly higher than in WGP I. It is only 2.7 % more expensive than the least-cost ration compared with 31.1 % cost increase of WGP II solution. In all three formulated diets mineral requirements are covered only with limestone and salt. This is due to rich mineral content assumed in used feedstuff.

The second fattening period has the highest average daily weight gain (1.1 kg/day) that result in the shortest fattening period. Linear program suggest very simple ration that is again the cheapest, but with 21.2 % energy surplus. Therefore protein-energy ratio is totally unbalanced. The second (WGP I) and the third daily ration (WGP II) differs from the parallel rations in the first period mostly in increased inclusion of grass and maize silage and decrease of soya meals and rapeseed cakes. From nutrition viewpoint most balanced ration (WGP I) in the second fattening period is 21.1 % more expensive than LP one, but total deviation is for 148 % reduced in comparison with LP and 51 % in comparison with WGP II. The latest ration is from nutrition viewpoint much better than LP solution, and for practice due to its simplification compared to WGP I and costs lowered by 18.6 % the recommended one.

For the third fattening period our tool yields solutions with comparable facts already pointed out. Cost of the feed included into ration plays significant role in LP's and WGP II solutions. WGP II yields better ration for the same daily price as LP. In this period the highest difference between ration costs is noticed. Expenditure of WGP I ration is for 65.6 EUR higher than in the case of still balanced WGP II ration during the third period only, and for the whole fattening period examined even 120 EUR per animal higher. This dif-

Table 3
Nutritive value of assumed feed

Indices	DM, g/kg	ME, MJ/kg DM	MP	CF	Ca	P	Mg	Na	K	Price/VC, cent
			g/kg DM							
Feed on disposal										
Hay	860	7.52	64.33	200	4.31	2.65	1.51	0.26	13.81	8.02
Grass silage	350	2.93	19.1	800	1.85	1.08	0.68	0.11	6.56	4.04
Maize silage	320	3.03	12.67	600	1.99	1.69	0.54	0.03	3.03	2.55
Grain maize	880	10.39	64.28	0	0.18	3.17	0.97	0.18	2.9	30
Soya meal	880	10.21	166.5	0	2.64	6.07	2.02	0.88	15.49	46
Rapeseed cake	900	9.75	99	0	2.29	5.54	2.2	1.76	7.92	37
Mineral and vitamin components										
MVM 1*	930	0	0	0	171.86	57.2	0	110.53	0	58.08
MVM 2*	930	0	0	0	130.94	81.84	29.46	98.21	0	67.56
Salt	950	0	0	0	0	0	0	334.4	0	50
Limestone	950	0	0	0	818.4	0	0	0	0	16.4

*Commercial names of mineral – vitamin mixtures are Bovisal 1 and Bovisal 2

ference is difficult to be outweighed by likely small increase of daily weight gains when WGP I solutions would be followed in practical feeding.

Discussion

The results showed that mathematical deterministic programming techniques can be successfully applied in the ration formulation process. In the presented analysis an example has been solved for illustration that utilised approach partly mitigates the mentioned drawbacks of LP (single objective function), which can still be useful to estimate the lowest possible fodder cost.

It is logical that daily ration costs are higher in both WGP solutions. Price increase is mostly dependent on weights set to cost function (I=1, II=100). In this paper we are presenting two extreme economic situations, while the solution to be followed in practice should be somewhere between both. Anyhow, economic weight is likely to be high, therefore close to 100.

The structure of the rations would be much different if all feed would be produced on the farm. Significant discrepancy is expected especially in LP and WGP II solutions, where feed cost has high importance.

Obtained rations are satisfactory, especially if we consider only foreseen nutrition requirements in initial version of the tool. But if we focus on micro elements and vitamins rations presented very likely do not meet animal requirements. This issue could be simple solved by setting new constraints for minimal incorporation of any (one) mineral-vitamin components (e.g. Bovisal 1 or Bovisal 2) into the ration. Their quantities are usually prescribed by producer.

Conclusions

Presented approach of combining linear programming with weighted goal programming enables to consider more than just one objective. This is becoming more important also in nutrition management and seems to be emphasised in line with general globaliza-

Table 4
Obtained results and daily rations formulated with LP and WGP scenarios

Duration, days	Fattening period, daily ration									Whole period (453 days)		
	First			Second			Third					
	LP	W GP I	W GP II	LP	W GP I	W GP II	LP	W GP I	W GP II	LP	W GP I	W GP II
	167			136			150			453		
Feed used, kg/day												
Hay	2	2	2	2	2	2	2		2	907.9	607.9	907.9
Grain maize		0.82			0.82			1.9		0	532.1	0
Maize silage	0.65	1.91	5.25	18.56	5.22	7.43	16.77	6.45	12.18	5.147.1	1 997.50	3 714.50
Grass silage	12.03	5.83	5.91	5.02	10.21	10.9	7.62	14.81	10.48	3.834.4	4 583.70	4 043.00
Soya meal	0.05		0.38			0.15				8.8	0	83.3
Rapeseed cake		0.59			0.18					0	122.8	0
Mineral components used, g/day												
Limestone	2.22	11.47	4.04		5.69	2.25		10.82	4,39	370.4	4 312.60	1.638.2
Salt	27.03	16.36	21.37	29.88	27.41	30.85	32.67	30.13	33.67	13 478.40	10 978.70	12.816.1
Price, cent/day	70	91.8	71.9	85.1	103.1	87.3	91.1	134.8	91.1			
Price, EUR	116.7	153.1	119.9	116.1	140.6	119	136.7	202.3	136.7	369.5	495.9	375.6
Price deviation from LP, %	0	31.1	2.7	0	21.1	2.5	0	48	0	0	34.2	1.7
Requirements deviations, %												
ME	1.1	0	0	21.2	0	0	6.7	0	0,0			
MP	0	0	-1	0	0	-1	0	0	-0.7			
Total deviation*	359.2	198	261	319.5	171.7	222.4	273.7	179.4	253			
Ratio between minerals												
Ca:P	1.7	1.6	1.5	1.5	1.5	1.5	1.6	1.5	1.5			
K:Na	10	10	10	10	10	10	10	10	10			
Physical ration attribute												
CF, %	25.8	19.8	23	22.3	21.9	23.9	22.8	19.7	23.6			
DM, kg/day	6.2	5.7	5.8	9.5	7.9	8.1	9.8	9	9.3			

* includes percentage deviation from requirements for ME, MP, DM, Ca, P, Mg, Na and K

tion impacts. Even though the tool presented is from nutrition viewpoint not very precise, the approach enables to formulate least-cost ration not taking too much risk of worsening its nutritive value. This type of risk could be mitigated by careful weights appointment. With more detailed set of nutrition constraints and goals the difference between the 'practical uses of the nominee ration' would be even higher in favour of weighted goal programming technique.

Results obtained by tool presented in the paper are directly applicable assuming there is 'perfect' data availability about costs, quantity and quality of feed on disposal. But we know this is never the case. Therefore one can address questions like: "How does variability in feedstuffs affect the decision we make in formulating rations?" This is definitely an interesting issue that should be answered. In the modelling sense it means to deviate from deterministic to stochastic concept.

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Combination of linear and weighted goal programming with penalty function in optimisation of a daily dairy cow ration

Kombinace lineárního a váženého cílového programování s trestnou funkcí při stanovení denní krmné dávky pro dojnice

J. Žgajnar, L. Juvančič, S. Kavčič

Biotechnical Faculty, University of Ljubljana, Biotechnical Faculty, Domžale, Slovenia

Abstract: The aim of the paper is to present a developed spreadsheet tool for the formulation of a daily dairy cow ration. It is constructed on the basis of two linked sub-models developed on the MS Excel platform. It merges the common linear programming model and the weighted-goal programming model with a penalty function. The first sub-model is included in the tool to make an estimate of the least-cost magnitude that might be expected. The obtained result is entered into the second sub-model as the goal that should be met as closely as possible. The tool was tested at two different values of preferential weights for dairy cows with a 25 kg daily milk yield. The results obtained confirm the benefits of the applied approach. In contrast to the common linear program tools, which terminate at formulation of the least-cost ration, our tool provides more efficient rations (in both economic and nutritive terms) by fine-tuning the nutritive goals and by allowing for harmless deviations from these goals by application of penalty functions.

Key words: spreadsheet ration optimization, economics of dairy breeding, linear programming, weighted goal programming with penalty function

Abstrakt: Cílem příspěvku je prezentace metodického tabulkového nástroje pro stanovení denní krmné dávky pro dojnice. Ten byl vytvořen na základě dvou propojených dílčích modelů na základě MS Excelu. Kombinuje běžný model lineárního programování a váženým cílovým programováním s trestnou funkcí. První submodel představuje nástroj k odhadu minimálních nákladů. Získané výsledky jsou vloženy jako cíl, jehož má být co nejtěsněji dosaženo, do druhého submodelu. Tento nástroj byl testován na základě dvou rozdílných hodnot diferenčních vah pro dojnice s denní dojivostí 25 kg. Získané výsledky potvrdily přednosti aplikované metody. Na rozdíl od běžných nástrojů lineárního programování, které končí formulací minimálních nákladů, předkládaný metodologický nástroj nabízí efektivnější denní dávky (jak v ekonomickém, tak nutričním smyslu) přesnějším vyvážením nutričních cílů a umožněním přijatelných odchylek od těchto cílů zavedením trestné funkce.

Klíčová slova: optimalizace krmné dávky, ekonomika produkce mléka, lineární programování, vážené cílové programování s trestnou funkcí

As in every economic activity, producers are seeking to produce in an economically efficient manner; this is also the case in dairy farming. Costs and revenues of dairy farming are influenced by numerous external factors relating to market conditions (such as the increase in feed prices), natural conditions (lower yields due to natural disasters or climate changes), or policy changes (milk quota increase and its future abolition). Due to the fact that forage costs already present up to 55% of the total variable cost, ration formulation is becoming the fundamental lever in dairy management. With the increasing volatility of fodder prices, this becomes an even more important issue.

Formulation of an efficient ration is a complex and time-consuming process. It should take into consideration nutritional, economic, and environmental factors. However, rations are most often constructed by experience, textbook-based knowledge, or by trial-and-error methods (by hand). In all these cases, non-nutritional factors, such as economics and the environment, might be neglected, which deteriorates the efficiency of diets.

Review of the existing literature offers numerous examples of utilizing operation research techniques for solving nutrition management problems. The most common is the least cost ration optimization based on linear programming (LP) technique, starting with Waugh (1951). As argued by Castrodeza et al. (2005), LP has until nowadays been most widely used in livestock ration formulation, which holds especially true for the blending industry.

Even though LP approach is suitable for solving nutrition management problems, it has some drawbacks and might therefore not be sufficient in formulation of a ration that would be effective in both economic and nutritive terms (Rehman, Romero 1984, 1987). Reasons for this lie in the very assumptions of the LP method: single-objective functions and fixed (rigid) constraints – right-hand side (RHS). This means that only one objective might be optimized at once (e.g., cost minimization). Ration formulation is quite a complex process, and the reduction of several objectives into only one – cost minimization – usually proves too rigid (Rehman, Romero 1984). Since nutrition management demands multi-objective consideration (Lara, Romero 1994), indirect impacts on the environment and animal well-being, which are usually negative, must be taken into consideration. The reduction of negative externalities is costly. In decision-making terms, this would lead to the problem where one would face several objectives that are usually in contradiction with one another.

The fact that all nutrient requirements are estimated on the basis of numerous equations' points at the second basic LP assumption – how nutrient constraint should be met – it assumes that no constraints' (e.g., given nutrition requirements) violence are allowed at all, irrespective of deviation level (Rehman, Romero 1984). In many real situations, this might manifest in fact that the LP model has no feasible solution. However, a relatively small relaxation in RHS would not seriously affect animal welfare, but it would result in a feasible solution (Rehman, Romero 1987; Lara, Romero 1994). This is especially true if we consider that the estimated nutritional requirements have also some deviations (errors).

One of the possible approaches to overcoming this drawback is to change all arbitrary 'conflicting' constraints, but Ferguson et al. (2006) are stating that this might manifest in an 'open' equation system, thus possibly yielding a meaningless solution. Besides that, expert knowledge is needed, and that could be the problem for the potential end user. Another problem concerning RHS is the fact that constraints are usually defined in only one direction. This could reflect in the rise of the primary costs or, what is lately becoming even more important, it could increase pollution with surplus elements and the greenhouse gas (GHG) emissions (Brink et al. 2001) due to unbalanced rationing at different stages. Imposing additional constraints could solve this drawback, but it could rapidly lead to an over-constrained and too complex model that has no feasible solution at all (Lara 1993).

When ration optimization is the case, the drawbacks mentioned might be reduced by the multi criteria decision making (MCDM) concept (Rehman, Romero 1984). The most pragmatic and commonly used method within the MCDM techniques is the weighed goal programming (WGP) (Tamiz et al. 1998). Its mathematical framework is familiar with the LP, which enables simplex algorithm utilization (Rehman, Romero 1993). Hence it follows that very commonly used spreadsheet program, such as the MS Excel, might be used as a basic platform. The latter is especially important when one tries to prepare an end-user optimization tool.

The objective of this paper is to present how mathematical programming techniques could be applied to prepare a user-friendly tool to support daily management tasks in the dairy sector. This also explains the reasoning for developing this tool in the MS Excel framework, since that software is available on most personal computers. After a brief overview of the optimization techniques and penalty function utilized, a short description of the applied approach follows. Then, the basic characteristics of the analysed case are presented followed by results and discussion. Brief conclusions close the last section.

MATERIALS AND METHODS

Weighted goal programming with a penalty function

The WGP technique enables one to optimize several objectives at once. Crucial objectives that are usually in contradiction might be converted into goals, and the remainder of the objectives can be considered as constraints. Rehman and Romero (1993) strongly recommend the use of sensitivity analysis, especially when one is not sure which objectives should be considered as goals. Theoretically, goals could be satisfied completely, partly, or in some extreme cases, some of them might also not be met. This violence is enabled by deviation variables. They are measured using positive and negative deviation variables that are defined for each goal separately, thus presenting over- or under-achievement of the goal. The WGP formulation is expressed as a mathematical model with a single objective (achievement) function. Since the objective function minimizes the sum of total deviation from set goals, the obtained result should yield compromise solution between contradictory goals. This is also the main difference between the LP and WGP since the objective function in the WGP paradigm minimizes the undesirable deviations from the target goal values and does not minimize or maximize goals themselves like in the LP (Ferguson et al. 2006).

The quality of the obtained results is therefore strongly dependent on the selection of preferential weights. Since any deviation is undesired, the relative importance of each deviation variable is determined by the belonging weights. They can be set either by expert estimation or with analysis of shadow prices. To reduce bias in the obtained result, an alternative technique to define weights could be used (Gass 1987).

Objectives set as goals are usually measured in different units of measurement and could not therefore be just summed up, because this would manifest in incommensurability (Tamiz et al. 1998). To overcome this issue, deviations are scaled by using the normalisation technique (desired-actual)/desired). Rehman and Romero (1987) emphasized that in the WGP, any marginal change within one goal is of equal importance (constant penalty) no matter how distant it is from the target value (Figure 1).

This addresses another issue in the ration formulation example. Namely, in some situations a too large deviation might fail to meet the animals' desired nutrition requirements, and thus the obtained solution will be useless. To keep deviations within the desired limits and to distinguish between different levels of deviations, the penalty function (Figure 1) might be introduced into the WGP (Rehman, Romero 1984).

Penalty function (PF) enables the fine-tuning of the positive and negative deviation intervals for each goal separately. Depending on the goal's characteristics (nature and importance of 100% matching), these intervals might be different (Figure 1). Sensitivity of PF is dependent on the number and size of the defined intervals and the penalty scale utilised (s_i for $i = 1$ to n). Namely, any deviation is treated on the basis of the predefined several-sided penalty function and cannot exceed the defined margins of the outer intervals. Since the PF is connected with the WGP through objective function, it is an important factor in minimizing the sum of total deviations.

Description of the tool

The presented tool has been developed as a spreadsheet in the MS Excel framework. It is structured as a two-phase model (sub-models) based on mathematical programming techniques (LP and WGP with PF). The first sub-model is a classical example of the least-cost ration formulation. Its purpose is to get a rough estimate of the ration cost, which is needed in the second sub-model (Figure 2). Since nutrition requirements might be in contradiction, especially in the case of higher daily milk yields, the first sub-model considers only the most important constraints.

The presented tool is developed as an open system, which means that all input data are recalculated for the analysed case. This is enabled by another model already developed (Žgajnar et al. 2007) that calculates the animals' daily requirements and is linked with the presented tool (Figure 2).

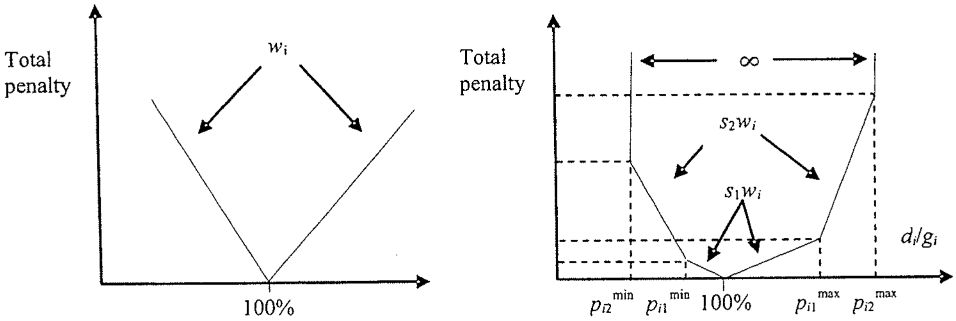

Figure 1. Scheme of the constant penalty and scheme of six-sided penalty function (adapted from Romero and Rehman, 2003)

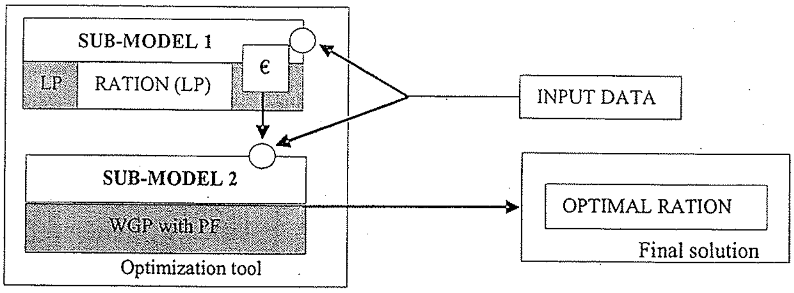

Figure 2. Scheme of the optimization tool

Mathematical formulation of the first and the second model

The first sub-model (LP) is formulated as shown in equations (1), (4), and (7). It mostly relies on economic (cost) function (C) and satisfies only the most important nutrition requirement coefficients (b_i). It might neglect some ratios (the tool has the option to switch them on or off), such as if the model is over-constrained and has no feasible solution. This is important since, when it happens, the second sub-model cannot yield a reasonable solution.

In the first optimization phase one is searching for the ration at the lowest possible cost (Figure 2). Except the minimum requirements that should be met, prices are the most important factor that dictates ration formulation. For on-farm produced forage, the total cost approach was considered, while for purchased feed, market prices were applied.

Equations of the first (LP) and the second sub-model (WGP with PF):

$$\min C = \sum_{j=1}^{n} c_j \times X_j \qquad (1)$$

$$\min Z = s_1 \sum_{i=1}^{k} w_i \frac{d_{i1}^- + d_{i1}^+}{g_i} + s_2 \sum_{i=1}^{k} w_i \frac{d_{i2}^- + d_{i2}^+}{g_i} \qquad (2)$$

$$\sum_{j=1}^{n} a_{ij} X_j + d_{i1}^- + d_{i2}^- - d_{i1}^+ - d_{i2}^+ = g_i \qquad (3a)$$

for all i = 1 to r and $g_i \neq 0$

$$\sum_{j=1}^{n} c_j X_j + d_{i1}^- + d_{i2}^- - d_{i1}^+ - d_{i2}^+ = C \qquad (3b)$$

for all i = 1 to r and $C \neq 0$

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \qquad (4)$$

for all i = 1 to m

$$d_{i1}^- \leq g_i - p_{i1}^{\min} g_i \qquad (5a)$$

for all i =1 to r

$$d_{i1}^- + d_{i2}^- \leq g_i - p_{i2}^{\min} g_i \qquad (5b)$$

for all i = 1 to r

$$d_{i1}^+ \leq p_{i1}^{\max} g_i - g_i \qquad (6a)$$

for all i = 1 to r

$$d_{i1}^+ + d_{i2}^+ \leq p_{i2}^{\max} g_i - g_i \qquad (6b)$$

for all i = 1 to r

$$d_{i1}^+, d_{i1}^-, d_{i2}^+, d_{i2}^-, X_j \geq 0 \qquad (7)$$

Where:

Z, C = objective function

a_{ij} = the quantity of the ith nutrient in one unit of jth feed

X_j = the level of jth feed

c_j = jth feed cost

b_i = the amount of the ith resource available – right hand side (RHS)

g_i = expected daily requirement of the ith nutrient (goal)

w_i = weight expressing the relative importance of achieving the ith goal

s_1 and s_2 = penalty coefficients for the first and the second level of over- or under achievement of the goal

d_{i1}^+, d_{i1}^-, d_{i2}^+, d_{i2} = positive and negative deviation variables including over- and under-achievement of the ith goal

$p_{i1}^{\min} < 1$, $p_{i1}^{\max} > 1$ = penalty function parameters defining first deviation interval of ith nutrient

$p_{i2}^{\min} < 1$, $p_{i2}^{\max} < 1$ = penalty function parameters defining second deviation interval of ith nutrient

The second sub-model (WGP with PF) is formulated as shown in equations (2) to (7). The objective (achievement) function (2) expresses the aggregate unwanted deviations and is therefore subject to minimization. It is defined as the weighted sum of deviations. Since the PF is in place also, its coefficients (s_1 and s_2) are considered. Preferences of defined goals are reflected by weights (w) associated with the corresponding positive or negative deviations. The scale of deviations is controlled through the defined penalty intervals (5a, 5b, 6a, 6b). Because of the normalization process, only goals that have nonzero target values (3a, 3b) could be relaxed; all the rest must be considered as fixed constraints (4). The obtained target value (C) in the first sub-model (LP) enters into the second one (WGP with PF) as the cost goal (3b) that should be met as close as possible. This is also the only case where negative deviation is not penalised and also not restricted with intervals. The main assumption of the linear programming is the non-negativity that is considered for the first sub-model ($X \geq 0$) as for the second one in equation (7).

Input data

The presented tool has been tested on a simple ration formulation example for a 650 kg dairy cow in the 150th day of lactation (total milk yield envisaged is 7 000 kg) with a daily milk yield of 25 kg and nutritional requirements for the 90th day of pregnancy. The most important constraints and goals for the analysed case are presented in Table 1.

A basic set of constraints (LP and WGP supported by PF) is more or less the same in both models. Nutritional constraints presented in Table 2 differ only in mathematical sign when nutrient requirements are transformed into goals. In the case when least-cost criterion is considered (LP), only the most important (non-conflicting) minimum or maximum constraints must be met. This might manifest in an 'unrealistic' diet. Nevertheless, this simplification has been made due to the fact that the LP module is needed foremost to give a rough estimation of the lowest possible diet cost. Undisputedly, an unbalanced ration is cheaper, and on one hand, this assures a feasible solution that is necessary, but on the other hand, the WGP with PF is encouraged to draw the price close to the one that might be achieved in practice.

In the everyday ration formulation process, one also has to consider constraints concerning quantities of feed, which must be included into the ration. In this case study, we assumed that the ration should include at least 3 kg of hay, but its quantity should not exceed 5 kg. Both sub-models should also not exceed the maximum quantity of grass and maize silage (Table 1).

Table 1. Daily nutrition requirements for dairy cow with 25 kg milk yield and requirements for 90th day of pregnancy, presented as constraints (LP) and set of goals in WGP

		Daily requirements summer/winter		Penalty function interval 1 (%)		Penalty function interval 2 (%)		w
		LP	WGP I / II	$s1-$	$s1+$	$s2-$	$s2+$	
NEL	(MJ)	> 122.4	122.4	0.5	0.5	5	5	100
MP	(g)	> 1 471.3	1 471.3	0.5	0.5	5	5	100
DM	(kg)	< 18.5	18.5	5	0	10	0	33
CF min	(kg)	> 3.3						
CF max	(kg)	< 4.8						
Ca	(g)	> 104.1	104.1	2	5	20	20	5
P	(g)	> 67.7	67.7	2	5	20	20	5
Ca : P	(%)	(1.5–2) : 1						
K : Na	(%)	(5.5–10) : 1						
Price	(cent)		C1	∞	10	8	20	5/95
Min hay	(kg/day)	3		∞				
Max hay	(kg/day)	5						
Max Grass silage	(kg/day)	30						
Max Maize silage	(kg/day)	30						
Max Salt	(g/day)	30						
Max Bovisal winter	(g/day)	240						
Max Bovisal summer	(g/day)	200						

Since the tool has been used to formulate both the winter and summer diet separately, there are also different quantities of the allowed mineral vitamin mixtures included (declared by the producer).

The initial version of the WGP model involves six goals supported by the PF (Table 1). The relative importance of each goal is defined with weights ranging between 0 and 100. As the most important goals to be met in our case, there are regarded the satisfaction of energy (NEL) and protein (MP) requirements (100), in both cases the deviation intervals are very restricted, since only 0.5% positive and negative deviations are allowed in the first stage and 5% in the second one. A much lower weight is foreseen for the dry matter intake that presents the consumption capacity. In this case, the deviation intervals are defined only for the underachievement of the goal, while for the practical reasons (consumption capacity), overachievement is not allowed. Besides that, an additional constraint is included to ensure that the proportion of dry matter derived from voluminous forage does not exceed 14 kg of DM. Since the nutritionists' doctrine ensures that it is more important to satisfy the ratio between Ca and P and also between K and Na than to meet the estimated mineral requirements, we consider relatively low weights for mineral (Ca, P) goals. All the remaining minerals are controlled through several safety measures, which prevent deficits as well as toxic concentrations.

With the applied approach we have tested how the 'optimal' ration would change due to different preferences concerning the cost goal. This analysis manifests in two scenarios. In the first scenario, the cost of the obtained ration (WGP I) was of minor importance ($w = 5$), while in the second scenario (WGP II), its importance was increased ($w = 95$). In both scenarios, the deviation intervals remain the same (+10% and +20%).

The ingredients assumed to be available for formulating the rations and their characteristics are given in Table 2. The described feed characteristics are mostly dependent on soil structure, application of fertilizers, and intensity of production. Consequently, high variability in nutrition quality might arise in practice. Due to this fact, a chemical analysis for each feed used (when analysing the practical case) should be performed to prevent errors in the formulated ration.

We assumed that all voluminous forage (hay, maize silage, grass silage, and grass) is produced on the farm. Of course grass might be included only in summer

Table 2. Nutritive value of feed on disposal

	DM (g/kg)	NEL (MJ/kg DM)	MP**	CF	Ca	P	Mg	Na	K	Price or TC* (cent/kg)
			(g/kg DM)							
Feed on disposal										
Hay	860	5.90	85.00	270	5.70	3.50	2.00	0.35	18.25	15.30
Maize silage	320	6.50	45.00	200	7.06	6.00	1.91	0.12	10.76	3.70
Grass silage	350	5.60	62.00	260	6.00	3.51	2.20	0.35	21.30	6.14
Grass	160	7.10	121.00	205	6.00	2.60	2.00	0.10	10.50	1.50
Maize	880	8.50	83.00		0.23	4.09	1.25	0.23	3.75	30.00
Wheat	880	8.60	88.00		0.57	3.86	1.59	0.45	5.00	32.00
Rapeseed cake	900	7.50	125.00		2.89	7.00	2.78	2.22	10.00	37.00
Soya meal	880	8.20	215.00		3.41	7.84	2.61	1.14	20.00	46.00
K-18***	880	7.61	136.74		10.23	5.68	2.84	3.98	10.23	27.67
K-19***	880	7.61	146.51		10.23	5.68	2.84	5.11	10.23	30.00
Mineral and vitamin components										
Limestone	950				400.00					16.40
MVM1****	930				160.00	100.00	36.00	120.00		67.56
MVM2****	930				210.00	70.00		135.00		58.08
Salt	950							400.00		50.00

*Total cost approach, **The lowest value of metabolisable protein is considered, ***Commercial names of dairy cows' feed containing different % of metabolisable proteins, ****Commercial name of mineral-vitamin mixtures are Bovisal summer and Bovisal winter rations. Since these forages are usually not tradable, we estimate the total cost of their production on the basis of 'model calculations' prepared by the Agricultural Institute of Slovenia (KIS 2007). All other forage and mineral-vitamin components on disposal could be purchased at market prices (Table 2). The question raised might be what should be grown on the farm to improve profitability, but this issue is very complex and is beyond the scope of the paper.

RESULTS AND DISCUSSION

The tool has been tested on a simple everyday example (650 kg dairy cow with a milk yield of 25 kg/day and 90th day of pregnancy). It was run four times, two times for the winter period and two times for the summer period, where grass was also at the cows' disposal. The formulated daily rations for both periods are presented in Table 3, including LP solutions. The latter serve only to estimate the diet least-cost and might not be really applicable since they are simplified.

There is a significant difference between the compositions of winter and summer rations, as well as the rations within each season (Table 3). The first difference is self-explanatory – there is grass available in the summer season – while the second difference manifests itself through different preferential weights and a PF in place.

In winter rations (WGP I and WGP II), protein requirements are mainly covered with grass silage and

Table 3. Obtained daily rations formulated with LP and WGP with cost penalty function scenarios

	Daily ration					
	winter			summer		
	LP	WGP I	WGP II	LP	WGP I	WGP II
Feed used (kg/day)						
Hay	5.00	5.00	5.00	4.56	3.00	5.00
Maize silage	25.16		10.33		15.18	17.22
Grass silage	6.14	23.84	16.57		5.80	0.16
Grass				69.23	34.58	32.08
Wheat	1.98	5.00	2.19			
Maize	1.18	1.50	1.50	1.95	1.50	1.50
Soya meal	2.30					
K-18			3.56	3.08		
K-19	0.17	1.56				
Mineral components used (g/day)						
Limestone		24.2	13.0		30.4	37.0
Bovisal Summer				104.6	56.8	50.2
Bovisal Winter	61.1	34.8				
Salt	30.0	30.0	28.1		30.0	30.0
Price (EUR/day)	3.87	4.34	3.87	2.66	2.93	2.91
Price deviation (%)	0.0	12.2	0.0	0.0	10.2	9.3
Requirements deviations (%)						
NEL	0.0	–1.7	–2.2	0.0	–0.5	–0.5
MP	0.0	0.0	0.0	39.0	0.0	0.0
Total deviation*	56.3	10.1	37.0	69.6	27.2	30.7
Physical ration attribute						
CF (%)	18	18	18	19	19	19
DM (kg/day)	18.5	18.5	18.5	17.8	18.0	17.9

*Total sum of deviations (including mineral deviations not presented in the table) purchased fodder K-19 (WGP I) and K-18 (WGP II). It is obvious that prices play a significant role since more restricted cost conditions (WGP II) have a significant impact on the inclusion of (expensive) grass silage. This is even more obvious in the summer season, where the main source of protein is much cheaper grass (WGP I) and some negligible quantity of grass silage (WGP II). Grass is therefore the crucial trigger for the difference between summer and winter rations composition. As already stated, the second difference is caused by preferential weights and the penalty system in place.

The penalty system enables one to control the deviations from the set target values (goals). The more severe cost penalty system (through higher relative importance $w = 95$) in the second scenario has a significant impact in both seasons from the nutrition quality aspect. Even though the WGP II rations are more balanced, in the summer season they are by 9.3% more expensive, while in the winter season, there is no difference in estimated cost at all. At a first glance, the least cost ration seems better, since the energy and protein requirements are fully met. Anyhow, if one considers also the sum of the total deviation as a measure of the 'quality' of obtained results, it is obvious that the WGP II ration is better than the LP's one, since the LP neglects some nutrition objectives. This fact is even more powerfully manifested in the first scenario (WGP I), where the importance of the cost goal is reduced ($w = 5$). As a result, prices increase in comparison to the second scenario for 0.9 to 12.2%, but total deviations (as a quality parameter) improve from 3.5 up to 26.9%, respectively. This could be explained as the competition between nutrition quality and economics. However, when rations are not balanced – even if the individual parameter requirements are fulfilled – one cannot expect to achieve the anticipated daily yields. This is especially true when very high (> 35 kg) daily milk yields are analysed.

CONCLUSIONS

The aim of this paper was to present a simple spreadsheet tool that can support daily management tasks – the dairy cow ration formulation. The applied approach – a combination of the LP paradigm and the WGP with PF – proves to be a useful 'engine' in an end-user application. It enables one to formulate close to least-cost ration, not taking a too high a risk of worsening the ration's nutritive value, which is the main common drawback of the LP. Rations might be additionally improved with fine-tuning enabled through the PF that differs between the deviation sizes for each goal separately. This significantly reflects in the obtained rations, especially in the summer season. This can be illustrated with the case presented in this paper, where the formulation of a daily ration only by the least cost criterion resulted in a 39% surplus of proteins in the summer ration, which might seriously affect the animals' health. In spite of a slightly higher price, cost efficiency can be improved through numerous factors. On one hand, surpluses cost money and have a negative impact on production (daily milk yields). On the other hand, they also increase greenhouse gas emissions (Brink et al. 2001).

General efficiency is becoming more and more important in nutrition management and this seems to be emphasised in line with the general globalization impacts (input price rise, price volatility, and environmental as well as climate change aspects). The developed tool might be useful also for the assessment of impact consequences by preparing calculations for different situations and technology types. It may also be useful in assessing variable costs of feed used or to provide an answer on different sector questions such as how market changes are affecting the 'optimal' animal diets through longer periods.

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Contact address:

Jaka Žgajnar, BSc, University of Ljubljana, Biotechnical Faculty, Zootechnical Department, Chair for Agricultural Economics, Policy and Law, Groblje 3, SI-1230 Domžale, Slovenia
e-mail: jaka.zgajnar@bfro.uni-lj.si

Žgajnar, J./ Kermauner, A./ Kavčič, S. Model za ocenjevanje prehranskih potreb prežvekovalcev in optimiranje krmnih obrokov. In: Slovensko kmetijstvo in podeželje v Evropi, ki se širi in spreminja, 4. konferenca DAES, Moravske toplice, 2007-11-08/09 (ed.: Kavčič, S.). Ljubljana, Društvo agrarnih ekonomistov Slovenije, Domžale, 2007, 278-288

MODEL ZA OCENJEVANJE PREHRANSKIH POTREB PREŽVEKOVALCEV IN OPTIMIRANJE KRMNIH OBROKOV

Jaka Žgajnar, Ajda Kermauner in Stane Kavčič*

Globalne spremembe močno vplivajo na upravljavske procese v kmetijstvu, ki so zato vse bolj podobni procesom ostalih gospodarskih sektorjev. Znotraj kmetijskega sektorja se nakazujejo postopne strukturne spremembe tudi z vidika bioenergetike. To v kmetijskem sektorju ustvarja dodatno povpraševanje, ki v pogojih zdrave konkurence vodi do višjih cen. Če pri trendu cen upoštevamo tudi šoke, povzročene z vse pogostejšimi naravnimi nesrečami, ugotovimo, da je posledično cenovno-stroškovno razmerje v živinoreji zelo nestabilno. Zato postaja pri slednji ključnega pomena dobro, natančno in hkrati hitro definiranje krmnega obroka, kar predpostavlja ustrezno določanje krmnih potreb in čim boljšo oceno hranilne vrednosti razpoložljive krme. Presežki in primanjkljaji posameznih hranljivih snovi rejcu namreč predstavljajo neposredno gospodarsko škodo, ki se z rastjo cen krme le še povečuje. V prispevku je predstavljen simulacijski model za izračunavanje krmnih potreb različnih kategorij živali pri različnih intenzivnostih reje in simulacijski model za vrednotenje hranilne vrednosti krme za prežvekovalce. Izračunane vrednosti simulacijskih modelov bomo uporabili kot tehnološke koeficiente pri optimiranju krmnega obroka in pri dopolnitvi že razvitega linearnega modela za optimiranje proizvodnih odločitev na kmetijskih gospodarstvih.

Ključne besede: prehrana živali, prežvekovalci, optimiranje obrokov, linearno programiranje, ciljno programiranje

*Biotehniška fakulteta Univerze v Ljubljani, Oddelek za zootehniko, 1230 Domžale, Groblje 3, jaka.zgajnar@bfro.uni-lj.si

ESTIMATION OF RUMINANTS' NUTRITIONAL REQUIREMENTS AND LIVESTOCK RATION OPTIMISATION

Global changes are having large impact on agricultural decision making process. Consequently it becomes similar to decision making in other business sectors. Within agriculture progressive structural changes are being indicated also from bio-energy point of view. As result additional demand in agricultural sector has been formed reflecting in upward price trends. If shocks caused by natural disasters, beside positive price trends, are taken into consideration, one can find out that price-costs relations in livestock sector are very unstable. For this reason good, precise and at the same time fast rations formulation in competitive livestock production is going to be of increasing importance, which means definition of corresponding nutrition needs and assessment of nutritional value of feeds available. Surplus or shortage of individual nutrients causes direct economic loss for breeder, what is especially emphasized when input prices are increasing. The paper presents a simulation model for assessment nutrient needs of different animal categories at different breeding intensities and simulation model for assessment nutritional value of different feeds for ruminants. Results obtained with these models are going to be used as technological coefficients in ration optimization and in completing of already developed linear model for production plans' optimization on agricultural holdings.

Keywords: animal nutrition, ruminants, ration optimization, linear programming, goal programming

Uvod

Profesionalizacija kmetijstva z deregulacijo trgov, rastočimi okoljskimi in družbenimi zahtevami ter posledicami klimatskih sprememb vodi v vedno večja tržna nihanja, od

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gospodarskih subjektov pa zahteva temeljitejše obvladovanje tveganj ter učinkovitejše načrtovanje gospodarjenja. Poleg tega se v celotni verigi kmetijskega sektorja kažejo strukturne spremembe. Evropska Strategija bio-goriv (Commission of the European Communities, 2006), Izvedbeni plan biomase (Commission of the European Communities, 2005) in sprejetje Direktive o bio-gorivih (Directive 2003/30/EC) s strani Komisije dajejo jasen signal, da EU želi podpreti bio-energetsko industrijo. Dautzenberg in sod. (2007) ugotavljajo, da je skupna kmetijska politika vse bolj naklonjena zmanjševanju pridelave hrane na račun povečevanja ne-prehranske pridelave. Zeller in Häring (2007) omenjata posledičen pozitiven vpliv dodatnega povpraševanja na zvišanje cen in s tem na ekonomsko situacijo poljedelcev. Z vidika živinoreje pa takšen trend nedvomno pomeni resen problem. Na podlagi Kataloga kalkulacij (Jerič, 2001) z revaloriziranimi cenami na leto 2006 smo izračunali delež spremenljivih stroškov krmnega obroka od skupnih spremenljivih stroškov pri različnih rejah. Ugotovili smo, da se deleži pri govedu gibljejo med 41 % in 71 %. To potrjuje našo hipotezo, da bo v prihodnje za dosego čim boljšega finančnega rezultata na živinorejskih kmetijah čedalje bolj pomembna cenovna optimizacija krmnega obroka in posredno tudi optimizacija primarne pridelave na obdelovalnih površinah. S tem kmetijski sektor postopno prevzema značilnosti ostalih gospodarskih sektorjev, kjer ekonomske zakonitosti predstavljajo osnovno vodilo nadaljnjega razvoja. Vodenje kmetijskega gospodarstva je tako vse bolj kompleksno in od upravljavca zahteva povezovanje znanja naravoslovnih in družboslovnih ved.

Za podporo pri odločanju na ravni kmetijskih gospodarstev v Sloveniji je bil že razvit deterministični statični linearni program (Žgajnar, 2006). Optimizacija je izvedena po načelu maksimiranja skupnega doseženega pokritja na ravni kmetije, ki jo opredelimo preko vnosa precej obširnega nabora podatkov in izklapljanja tistih aktivnosti, ki na konkretnem gospodarstvu niso realna alternativa. Model je namenjen predvsem živinorejsko usmerjenim kmetijskim gospodarstvom, ki se ukvarjajo z rejo prežvekovalcev. Pri testiranju modela se je izkazalo, da je optimizacija proizvodnje z vnaprej izbranim krmnim obrokom precej okrnjena (Žgajnar in sod., 2007). Optimizacija krmnega obroka je eden izmed ključnih dejavnikov, ki širi manevrski prostor za izboljšanje ekonomskega položaja. Da bi rejci prežvekovalcev lažje ocenili potrebe svojih živali, smo v Excelovem okolju pripravili simulacijski model za ocenjevanje dnevnih in letnih potreb po hranljivih snoveh v odvisnosti od intenzivnosti prireje. Nepoznavanje dnevnih potreb in krmne vrednosti obroka namreč lahko vodi v preskromno ali pa prekomerno prehrano, oboje pa rejcu predstavlja gospodarsko škodo. Z metodami matematičnega programiranja lahko pripravimo orodje, ki omogoča optimizacijo krmnega obroka na podlagi minimiziranja stroškov ob hkratnem povečevanju učinkovitosti izkoriščanja krme. Tovrstni izračuni so lahko v pomoč rejcu pri izračunu potrebnih količin, vrste in kakovosti doma pridelane krme za vnaprej predvideno intenzivnost reje.

V prispevku podajamo pregled uporabe metod linearnega programiranja za reševanje prehranskih problemov in predstavljamo 'vmesni' model za izračuna dnevnih in letnih potreb posameznih kategorij domačih živali pri različnih intenzivnostih prireje. Rezultati vmesnega modela, ki bodo za posamezna kmetijska gospodarstva precej različni, bodo predstavljali vhodne podatke pri ekonomski optimizaciji letnega krmnega obroka, primerni pa bodo tudi za večstopenjsko reševanje klasičnih prehranskih problemov s pomočjo nadgrajenega linearnega programa v ciljni program.

Pregled literature

Tehnike linearnega programiranja za načrtovanje prehrane

Žgajnar, J./ Kermauner, A./ Kavčič, S. Model za ocenjevanje prehranskih potreb prežvekovalcev in optimiranje krmnih obrokov. In: Slovensko kmetijstvo in podeželje v Evropi, ki se širi in spreminja, 4. konferenca DAES, Moravske toplice, 2007-11-08/09 (ed.: Kavčič, S.). Ljubljana, Društvo agrarnih ekonomistov Slovenije, Domžale, 2007, 278-288

Orodje linearnega programiranja je klasično orodje za reševanje najrazličnejših prehranskih problemov tako na področju humane prehrane kot pri uravnavanja krmnih obrokov vseh vrst domačih živali (Darmon in sod., 2002). Pri humani prehrani se linearno programiranje uporablja za reševanje najrazličnejših problemov, od iskanja najokusnejšega obroka (Smith VE, 1995; Fletcher in sod., 1994), definiranja diete za individualnega pacienta v bolnišnicah, reševanja lakote v državah tretjega sveta, iskanja najcenejše prehrane za brezdomce (Holcomb in DePorter, 1990) in vse do iskanja najcenejšega obroka (Rozman in sod., 2002). Darmon in sod. (2002) ugotavljajo, da se linearni program lahko uporabi tudi za iskanje prehranskih predlogov in omejujočih hranil, pa tudi za oceno, ali je primerno prehransko dieto mogoče doseči z lokalno dosegljivo hrano v različnih sezonah. Kombinacijo linearnega programa z nelinearnim programom so uporabili za analizo pomena (izraženo z Langrangovimi multiplikatorji) posameznih tudi nelinearnih omejitev.

Optimizacijski model je definiran z namensko funkcijo, ki je odvisna od nabora vključenih spremenljivk in omejena z različnimi omejitvami. Cilj optimiranja je poiskati nabor spremenljivk, ki dajo optimalno vrednost namenske funkcije in hkrati zadostijo vsem predpostavljenim omejitvam. V literaturi zasledimo številne prehranske modele, ki optimirajo bodisi dieto ali krmni obrok s številnih vidikov. Najpogostejši so modeli iskanja najcenejšega krmnega obroka, zasledimo pa tudi modele, ki ocenjujejo vrednost krme na podlagi razpoložljive energije za rastoče živali (Magowan in O'Callaghan, 1986), minimizirajo čas krmljenja pri divjadi (Nolet in sod., 1995), minimizirajo količino zaužite energije (Darmon in sod., 2002) ali pa minimizirajo absolutno razliko (MOTAD) med povprečnim obrokom določene socio-ekonomske skupine in sestavljeno dieto na podlagi prehranskih priporočil (Darmon in sod., 2006). Pri reševanju prehranskih problemov s pomočjo klasičnega linearnega programa pogosto naletimo na problem kontradiktornih ciljev. Rezultat slednjih je, da model ne najde možne rešitve ali pa je teh neskončno mnogo. V takšnem primeru je problem rešljiv le, če arbitrarno spremenimo omejitve (Ferguson in sod., 2006). Model je zato zelo fleksibilen in v določenih primerih lahko pripelje do nerealne rešitve (Rehman in Romero, 1984). Da bi zaobšli to pomanjkljivost klasičnega linearnega programa, ga je v nekaterih primerih smiselno nadgraditi v večkriterijalni - ciljni program (Rehman in Romero, 1984, 1987; Pablo, 1993; Ferguson in sod., 2006). V tem primeru nam izbrani nivoji hranil predstavljajo cilje in ne več omejitve, kot so to v klasičnem linearnem programu za iskanje najcenejšega krmnega obroka. Poleg tega lahko dodamo tudi druge cilje, s katerimi poizkušamo rešitev približati realnosti. Castrodeza in sod. (2005) pri načrtovanju krmnega obroka poleg minimalnih stroškov poizkušajo zagotoviti tudi čim boljšo učinkovitost krmnega obroka, ob hkratnem minimiziranju negativnih vplivov na okolje. V živinoreji je to lahko na primer tudi osnovanje krmnega obroka na pretežno doma pridelani krmi. Dobljena optimalna rešitev nam pri večkriterjalnem programiranju tako predstavlja kompromis med kontradiktornimi cilji. Opredeljeni so s pomočjo pozitivnih in negativnih odstopanj od zastavljenih ciljev. Njihov relativen pomen je definiran s pomočjo uteži k pripadajočemu pozitivnemu oziroma negativnemu odstopanju. Tehtana vsota odstopanj nam definira namensko funkcijo, ki je predmet minimizacije. Tako nadgrajen klasičen linearni program omogoča večjo fleksibilnost in v večini primerov pripelje do realnejše rešitve. S ciljnim programiranjem torej minimiziramo neželeno odstopanje od zastavljenih ciljev in ne minimiziramo oziroma maksimiramo ciljev samih (Ferguson in sod., 2006). Kvaliteta modela je tako v največji meri odvisna od definiranja zastavljenih ciljev. Zato je pri takšnem modeliranju nujno sodelovanje strokovnjakov z vpletenih področij ali celo uporaba druge metode za čim manjšo pristranskost pri definiranju uteži (Gass, 1987).

Linearnost in nelinearnost pri reševanju prehranskih problemov

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Pri reševanju prehranskih problemov se pogosto srečamo z nelinearnimi omejitvami. Eden takšnih primerov je omejitev, izražena kot razmerja hranil oziroma mineralov (Darmon in sod., 2002). Da zadostimo pogojem linearnosti, moramo s pomočjo ustreznih matematičnih transformacij takšno razmerje prevesti v linearno omejitev. Model je namreč linearen le, če so vse omejitve, znotraj katerih iščemo rešitev, linearne, in je nelinearen, če je ena ali več omejitev nelinearnih. Tudi v primeru neekonomske, a hkrati linearne optimizacije krmnega obroka se lahko srečamo z nelinearno ciljno funkcijo. Takšen primer je minimiziranje absolutnega odstopanja pri večstopenjskem pristopu sestavljanja krmnih obrokov.

Material in metode

Opis zasnove simulacijskega modela

Simulacijski model je namenjen izračunavanju prehranskih potreb za različne kategorije goveda in drobnice. Izračunane vrednosti bodo služile kot vhodni podatki pri optimizacijskem modelu. Govedo smo zajeli s kategorijami krav molznic, krav dojilj, telic, telet ter treh pasem govejih pitancev, ki se najpogosteje pojavljajo na slovenskih kmetijah. Drobnico pa zastopajo mlečna in mesna usmeritev reje ovac.

Pri izračunu krmnih potreb smo se omejili na oceno konzumacijske sposobnosti in na potrebe po energiji, beljakovinah ter minimalni in maksimalni strukturni surovi vlaknini. Za ocenjevanje energijske vrednosti krme in za ocenjevanje oskrbljenosti prežvekovalcev z energijo se je v preteklosti uporabljal sistem škrobnih enot (Žgajnar, 1990). Zaradi nekaterih pomanjkljivosti tega sistema se sedaj v Sloveniji uporablja nemški sistem, ki za krave molznice izračunava potrebe v neto energiji za laktacijo (NEL), za plemensko govedo, govedo v pitanju in za ovce pa v presnovljivi energiji (Verbič in Babnik, 1999). Prehranski model izračunava energijske potrebe na podlagi enačb in normativov za posamezno obdobje reje (Verbič in Babnik, 1999). Potrebe po beljakovinah pri prežvekovalcih ocenjujemo na podlagi presnovljivih beljakovin. Normative in enačbe za izračunavanje potreb prežvekovalcev v različnih obdobjih proizvodnega cikla smo prav tako povzeli po priporočilih Verbiča in Babnika (1998).

Osnovno izhodišče za izračun krmnega obroka in za učinkovito vodenje prehrane je definiranje količine krme, ki jo žival lahko poje. Na podlagi obsežnih raziskav v svetu in pri nas lahko danes dokaj točno napovemo konzumacijsko sposobnost živali (Orešnik, 1996). Odvisna je predvsem od pasme, obdobja proizvodnega cikla živali, obsega prireje in telesne mase. Za krave molznice in krave dojilje jo izračunamo na podlagi Forbesovih formul, ki so bile v slovenskih razmerah že preverjene (Orešnik, 1994). Pri teletih in govejih pitancih sposobnost za zauživanje suhe snovi ocenimo na podlagi telesne mase (Žgajnar, 1990). Podobne zakonitosti veljajo tudi pri prehrani drobnice, le da je razmerje med teoretično sposobnostjo za zauživanje krme in telesno maso nekoliko širše (Kermauner, 1996). Da bi se kar najbolj približali izračunani sposobnosti za zauživanje suhe snovi, je potrebno zagotoviti ustrezno kakovost krme, ki nenazadnje vpliva tudi na končen rezultat prireje. Razvit prehranski model zajema le ključna dejavnika kakovosti voluminozne krme in sicer dovoljeno najvišjo in zahtevano najnižjo vsebnost surove strukturne vlaknine. S tem po eni strani zagotovimo ustrezno kakovost, po drugi strani pa normalno delovanje predželodcev in vseh bioloških procesov, ki so s tem povezani. Minimalne in maksimalne vrednosti smo za govedo povzeli po Žgajnarju (1990), za drobnico pa po Kermauner (1996).

Potrebe po hranljivih snoveh so navadno podane za posamezna obdobja reje (Verbič in Babnik, 1999; Verbič in Babnik, 1998; Kermauner, 1996; Orešnik, 1996; Žgajnar 1990), kar pomeni, da je za pridobitev vrednosti za enoletno ali drugo ustrezno časovno obdobje potrebno izračune združevati in v nekaterih primerih tudi nekoliko korigirati. Dodaten tehnični izziv predstavlja izračunavanje potreb po energiji in presnovljivih beljakovinah. Potrebe se namreč računajo ločeno za vzdrževanje, brejost, mlečnost, prirast, hujšanje, nalaganje telesnih rezerv in pri drobnici tudi za rast volne. Pri pitancih se denimo zaradi rasti, ki je odvisna od dnevnega prirasta, potrebe za vzdrževanje nenehno povečujejo. To povečevanje pa ni nujno enakomerno, saj se v obdobju pitanja spreminja dnevni prirast, posledično pa se telesna masa ne povečuje linearno. Do podobnih navzkrižnih odvisnosti pridemo pri vzreji plemenskih živali. Pri mlečnih rejah prihaja do razlik predvsem v nalaganju in sproščanju telesnih rezerv ter v dobi med telitvama, v obeh primerih tudi kot posledica količine prirejenega mleka. Hkrati se količina prirejenega mleka s trajanjem laktacije spreminja. Da čim bolje zajamemo opisano kompleksnost v modelu, je potrebno izračunavati dnevne potrebe znotraj celotnega (največkrat enoletnega) obdobja in jih nato sešteti.

Simulacijski prehranski model za izračunavanje krmnih potreb je izdelan tako, da omogoča izračunavanje povprečnih dnevnih potreb, potreb na točno določen dan znotraj proizvodne dobe, potreb v definiranem obdobju sezone, potreb v celotnem obdobju pitanja ali vzreje oziroma v enem letu glede na vnaprej definirane proizvodne lastnosti. Na podlagi slednjih model izračuna tudi predvideno dobo vzreje plemenskih živali in živali v pitanju. S takšnim pristopom je omogočeno obravnavanje različnih tehnologij reje in vzreje, s katerimi se v praksi srečujemo. Posebna pestrost tehnologij je prisotna pri govejih pitancih, pri katerih se ta odraža poleg pestre pasemske strukture predvsem v različnih začetnih masah pitanja in intenzivnosti pitanja. Slednja se odraža tako v povprečnem dnevnem prirastu, dobi pitanja, kot tudi v klavno zreli telesni masi.

Samo robusten in uporabnikom prijazen vmesnik omogoča hitro in enostavno nastavitev modelov za izračunavanje želenih spremenljivk. To smo dosegli z združitvijo najpomembnejših parametrov na posebnem listu, ti parametri pa se v naslednji stopnji vključujejo v posamezne podrobnejše izračune. Tak vmesnik od potencialnih uporabnikov ne zahteva podrobnega poznavanja uporabljenih funkcijskih pristopov, pač pa le nekatere bistvene zakonitosti živinoreje. Npr. pri večjih prirastih so pitanci prej klavno zreli in zato je tudi pričakovana končna telesna masa nekoliko nižja kot bi bila pri nekoliko manjših dnevnih prirastih. V simulacijskem modelu zajete proizvodne parametre, ki jih lahko spreminjamo in vplivajo na izračune prehranskih potreb, prikazujemo v preglednici 1. Nabor vhodnih podatkov med kategorijami se seveda razlikuje.

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Preglednica 1: Vhodni podatki simulacijskega prehranskega modela

Vhodni podatki	Krave molznice	Krave dojilje	Teleta	Telice	Pitanci	Ovce za mleko	Pitanje jagnjet
	Kategorija živali						
Telesna masa	✓	✓				✓	
Začetna telesna masa			✓	✓	✓		✓
Končna telesna masa			✓	✓	✓		✓
Sproščanje in nalaganje telesnih rezerv	✓	✓				✓	
Obdobje sproščanja in nalaganja telesnih rezerv	✓	✓				✓	
Obdobje brejosti	✓	✓		✓		✓	
Laktacijska doba	✓	✓				✓	
Doba med telitvama	✓	✓					
Povprečen dnevni prirast I			✓	✓	✓		✓
Povprečen dnevni prirast II				✓	✓		
Skupna mlečnost	✓	✓				✓	
Sestava mleka (% maščob in beljakovin)	✓	✓				✓	
Št. telet/jagnjet		✓				✓	
Rojstna masa telet/jagnjet	✓	✓				✓	
Pasma	✓	✓			✓	✓	

Sestavljanje krmnih obrokov

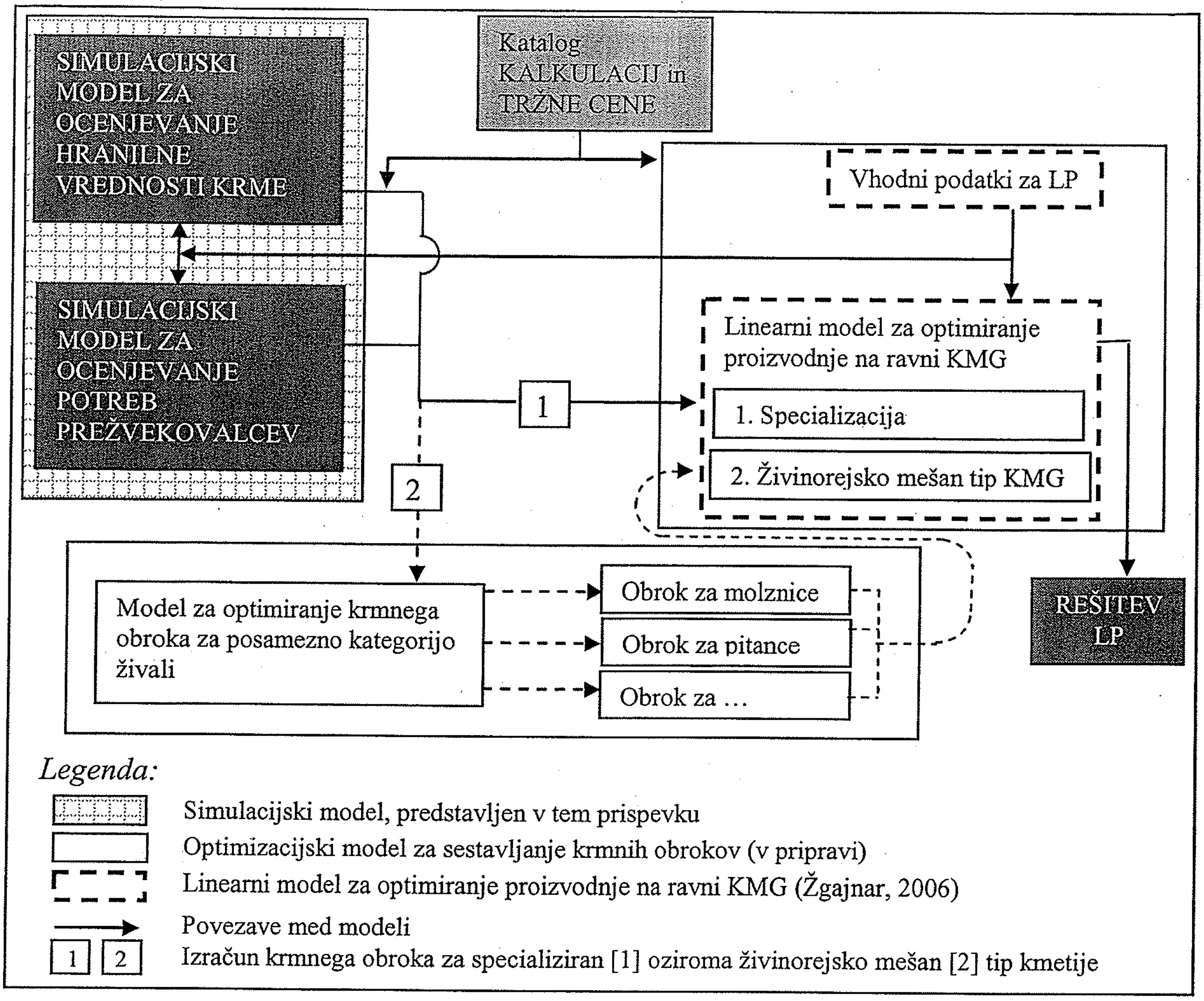
Pri vodenju prehrane različnih kategorij domačih živali se v praksi srečujemo z različnimi sistemi krmljenja. Bistvena razlika med njimi je v ciljih reje oziroma prireje, velikosti kmetijskih gospodarstev, možnostih za pridelavo voluminozne in močne krme in nenazadnje tudi od ukrepov kmetijske politike, ki posredno ali neposredno favorizirajo določen tip gospodarjenja (Žgajnar in sod., 2007). Ti dejavniki so toliko izrazitejši, ko gre za ekonomsko optimizacijo gospodarjenja na kmetijskih gospodarstvih. Razvit simulacijski model poleg krmnih potreb živali izračunava tudi krmno vrednost različnih vrst krme, ki jo bodisi pridelamo na kmetijskih površinah, bodisi kupimo. Ocena hranilne vrednosti krme za prežvekovalce je v večjem delu povzeta po Verbiču in Babniku (1998). V nekaterih primerih je razpoložljiva energija krme izražena le v neto energiji za laktacijo. Zaradi manjkajočih podatkov je pogosto ni možno preračunati v metabolno energijo, s katero operiramo pri (ostalih) prežvekovalcih, ki prvenstveno niso namenjeni prireji mleka. Manjkajoče podatke za izračune smo povzeli po nemških prehranskih tabelah (DLG, 1997).

Simulacijski model skupno zajema 92 ocen vrednosti različnih vrst krme za prežvekovalce, ki jo kmet lahko pridela na lastnih površinah ali dokupi. Dobljeni podatki zadostujejo za neekonomsko optimizacijo krmnega obroka, kar pomeni, da ne spremljamo stroškovnega vidika. Potrebno je le definirati razpoložljive vrste krme in njihove količine ter obdobje in način spravila. Uporabljena tehnika matematičnega programiranja je odvisna od narave problema in pristopa k njegovemu reševanju. Pri pregledu literature smo ugotovili, da sta najpogosteje uporabljena deterministično statično linearno programiranje in večkriterijalno oziroma ciljno programiranje.

Dejstvo, da je ekonomska uspešnost živinoreje v največji meri odvisna od spremenljivih stroškov krme, narekuje stroškovno optimizacijo krmnega obroka. Torej je za opazovane parametre (NEL, ME, suha snov, minimalna in maksimalna vsebnost strukturne surove vlaknine) potrebno izračunati spremenljive stroške za vsako vrsto krme posebej. Ta korak zahteva pripravo podrobnih kalkulacij, na podlagi katerih je mogoče oceniti stroške za kilogram posamezne krme pri različnih tehnologijah in intenzivnostih pridelave. Tako ovrednotene hranilne vrednosti posamezne krme bodo omogočale ekonomsko optimizacijo krmnega obroka. Naša naslednja naloga je torej pripraviti takšen optimizacijski program, ki bo minimiziral stroške krmnega obroka.

Linearni program za optimiranje proizvodnih odločitev na ravni kmetijskih gospodarstev (Žgajnar, 2006) bomo v prehranskem delu nadgradili z razvitim simulacijskim modelom (slika 1). S tem bomo nadomestili vnaprej definirane potrebe po posamezni vrsti krme s potrebami po posameznih hranljivih snoveh. Model bo omogočal sestavljanje krmnih obrokov na ravni cele kmetije. To bo razmeroma enostavno v primeru, ko gre za specializirano kmetijo (postopek 1), za katero bo model sestavil krmni obrok le za dotično kategorijo domačih živali. Precej zahtevnejši postopek pa bo potrebno ubrati pri živinorejsko mešanem tipu kmetij (postopek 2), na katerih krmnega obroka posamezne kategorije živali ne bo možno vnaprej definirati. Hkrati se pojavi problem pri močni krmi, ki je namenjena le določeni kategoriji domačih živali. Problema se bomo lotili z dvostopenjsko optimizacijo. V prvi fazi bomo optimirali krmni obrok za posamezno kategorijo domačih živali izven optimizacijskega modela. Na podlagi vhodnih podatkov kmetije bomo definirali aktivnosti pridelave krme, ki so v danem primeru realno možne. Na osnovi predvidenih pridelkov in načina spravila bomo poleg hranilne vrednosti iz baze kalkulacij dobili tudi oceno o spremenljivih stroških na enoto proizvodnje. Za vsako kategorijo domačih živali bomo tako razvili samostojen optimizacijski model, ki bo iskal najcenejši krmni obrok. Dobljene rešitve bomo upoštevali v drugi fazi iskanja optimalne rešitve, v kateri bomo s pomočjo že razvitega linearnega programa (Žgajnar, 2006) optimirali proizvodnjo na ravni cele kmetije.

Žgajnar, J./ Kermauner, A./ Kavčič, S. Model za ocenjevanje prehranskih potreb prežvekovalcev in optimiranje krmnih obrokov. In: Slovensko kmetijstvo in podeželje v Evropi, ki se širi in spreminja, 4. konferenca DAES, Moravske toplice, 2007-11-08/09 (ed.: Kavčič, S.). Ljubljana, Društvo agrarnih ekonomistov Slovenije, Domžale, 2007, 278-288



Slika 1: Shema povezave simulacijskega modela z linearnim modelom za optimiranje proizvodnih usmeritev na ravni kmetijskih gospodarstev in postopek dvostopenjske optimizacije krmnega obroka

Da bi ugotovili, kako se s takšnim pristopom spremeni dobljena optimalna rešitev na konkretnem kmetijskem gospodarstvu, bo potrebna dodatna analiza. Če se bo izkazalo, da je takšen pristop optimizacije preveč pristranski in nas hkrati ne bo zanimala sestava krmnega obroka, bomo v drugi fazi optimiranja upoštevali le hranilne vrednosti in cene za krmne mešanice, ki z že omenjenega vidika predstavljajo problem.

V prehranskem delu razširjen in natančnejši model bo omogočal dodatne analize s področja ekonomike prehrane. S ponovnim definiranjem namenske funkcije bomo naredili primerjalno analizo med optimalno rešitvijo, ki jo dobimo pri maksimiranju pokritja in med optimalno rešitvijo, če namenska funkcija predstavlja minimiziranje krmnih stroškov. Pričakujemo, da bo ob istih omejitvah korelacija med dobljenimi rešitvami zelo visoka.

Sklep

Menimo, da bi moralo biti iskanje najcenejšega krmnega obroka, ki hkrati pokrije vse potrebe živali, temeljno vodilo vsakega sodobnega živinorejca. Temu v prid govori dejstvo, da stroški krmnega obroka pogosto presegajo polovico, ob visokih cenah krmnih žit pa pri nekaterih kategorijah goved celo dve tretjini skupnih spremenljivih stroškov. Le enostaven, a hkrati dovolj natančen program za izračunavanje krmnih potreb bo rejce prepričal v smiselnost pogostejšega izračunavanja potreb njihovih živali. S primernim optimizacijskim programom

Žgajnar, J./ Kermauner, A./ Kavčič, S. Model za ocenjevanje prehranskih potreb prežvekovalcev in optimiranje krmnih obrokov. In: Slovensko kmetijstvo in podeželje v Evropi, ki se širi in spreminja, 4. konferenca DAES, Moravske toplice, 2007-11-08/09 (ed.: Kavčič, S.). Ljubljana, Društvo agrarnih ekonomistov Slovenije, Domžale, 2007, 278-288

bodo lahko sestavljali cenejše krmne obroke, ki bodo v danih ekonomskih in tržnih pogojih za njihovo rejo ekonomsko najugodnejši.

Rejec bi s pomočjo takšnega programa dosegel tudi večjo alokacijsko učinkovitost, saj bi lahko vnaprej načrtoval, katere kulture so zanj v danih pogojih najbolj donosne, in bi svoje proizvodne vire lahko razporedil tako, da bi kar najbolje pokril potrebe svojih živali. Prav alokacijska učinkovitost pa je poleg tehnične učinkovitosti ključen element ekonomske učinkovitosti (Farrell, 1957).

Pri takšnem pristopu gre za podporo kratkoročnim odločitvam, ki pa pogosto lahko podkrepijo dolgoročno načrtovanje in usmeritev kmetijskih gospodarstev. Zgrajen program za simuliranje prehranskih potreb prežvekovalcev bi bilo zato v prihodnje smiselno razširiti tudi na izračunavanje potreb za neprežvekovalce. Pri njih je namreč ekonomika reje zaradi velikega deleža žit in močne krme v obroku še toliko občutljivejša na močna nihanja cen teh komponent obroka, ki jih rejci pogosto dokupujejo. Optimizacija prehrane bi zanje lahko pomenila precejšnje znižanje stroškov in s tem izboljšanje ekonomskega položaja. Naknadno bi kazalo zgrajen linearni program razširiti na dodatne živinorejske aktivnosti in ga s tem približati večjemu številu kmetijskih gospodarstev v Sloveniji.

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SPREADSHEET TOOL FOR LEAST-COST AND NUTRITION BALANCED BEEF RATION FORMULATION

Jaka ŽGAJNAR and Stane KAVČIČ

Univ. of Ljubljana, Biotechnical Fac., Dept. of Animal Science, Groblje 3, SI-1230 Domžale, Slovenia, e-mail: jaka.zgajnar@bfro.uni-lj.si.

ABSTRACT

This paper points out some facts that might improve economic outcome of livestock production in the sense of diet formulation. A spreadsheet tool from two linked modules based on MS Excel platform was constructed, merging different mathematical deterministic programming techniques. The first module utilizes linear program for least-cost ration formulation, aiming to obtain rough estimate what magnitude of the costs might be expected. Resulting value is then considered as target value of cost goal in the second module. It is based on weighted goal programming with penalty function. Obtained results confirm benefits of applied approach. It enables formulation of least-cost ration not taking to much risk of worsening the ration's nutritive value and balance between nutrients. This is especially important when improved economic and nutritive efficiency is the primal and common aim of optimization tool.

Key words: cattle / bulls / spreadsheet tools / beef economics / beef ration optimization / linear programming / weighted goal programming / penalty function

ORODJE ZA NAČRTOVANJE NAJCENEJŠIH IN PREHRANSKO IZRAVNANIH OBROKOV ZA PITANCE

IZVLEČEK

Prispevek izpostavlja nekatere dejavnike, ki z vidika sestavljanja krmnih obrokov lahko izboljšajo ekonomiko živinoreje. V Excelovem okolju je bilo v obliki elektronskih preglednic razvito modularno orodje, ki združuje različne tehnike determinističnega matematičnega modeliranja. Prvi modul vključuje tehniko linearnega programiranja in služi za oceno najcenejšega možnega krmnega obroka. Dobljeni rezultat kot ciljna vrednost vstopa v drugi modul, ki temelji na tehtanem ciljnem programiranju, nadgrajenem s kazensko funkcijo. Pridobljeni rezultati potrjujejo prednosti uporabljenega pristopa, ki omogoča sestavljanje najcenejših krmnih obrokov, ne da bi ob tem tvegali močnejše poslabšanje hranilne vrednosti in razmerja hranil. To je posebej pomembno, ko je izboljšanje ekonomske in prehranske učinkovitosti temeljni cilj optimizacijskega orodja.

Ključne besede: govedo / biki / pitanje / elektronsko orodje / ekonomika / optimiranje prehrane / linearno programiranje / tehtano ciljno programiranje / kazenska funkcija

INTRODUCTION

Due to changing economic and political environment, the beef sector is becoming one of the most sensible agricultural sectors in the European Union. Its economic position is mostly dependent on the efficiency of each agricultural holding production structure, with the crucial role playing the economy of scale. However, at the moment poor economics position of beef sector could be significantly imposed with progressive abolition of previous Common Agricultural Policy (CAP) production coupled support and increasing environmental and other public demands - in addition to World Trade Organization (WTO) pressures, which have led to rapid market fluctuations. Together with direct consequences on the beef market, there are indirect influences that are going to present an increasing economic challenge for beef farmers, especially through higher input prices. Since ration costs might present 40 to 70 % of total variable costs, it follows that livestock ration formulation is becoming an increasingly important task also in management of beef sector. It is the fundamental lever in technological improvement that manifests in economic as also ecological terms. In order to help breeders to deal with these challenges many tools have been developed.

The most frequent technique applied is deterministic linear programming (LP). It is a classical approach to formulate animal diets and also appropriate tool to optimize human nutrition (Darmon *et al.*, 2002). When focusing only on livestock diets, one can find out that the most frequent manner of utilizing LP technique is least-cost ration formulation, for the first time used by Waugh (1951). As any optimisation technique also LP has some drawbacks.

Common to all LP problems is single objective function as its basic concept. It means that one try to get the optimal solution in minimizing or maximizing desired objective within set of constraints imposed. From this point of view LP could be deficient method for ration formulation, since it exclusively relies on one objective (cost function) as the only and the most important decision criteria (Rehman and Romero, 1984; 1987). Lara and Romero (1994) are stressing that in practice decision maker never formulates ration only on the basis of a single objective, but rather on the basis of several different objectives, where economic issue is only one of many.

Another drawback of pure LP is also mathematical rigidity of constraints (right hand side - RHS), which usually results in fact that set of equations does not have a feasible solution (Rehman and Romero, 1984). This means that no constraints' (e.g. given nutrition requirements) violence is allowed at all, irrespective of deviation level. However, relatively small deviations in RHS would not seriously affect animal welfare, but would result in a feasible solution (Lara and Romero, 1994).

The most appropriate and commonly used method that partly overcomes listed problems of LP paradigm is weighted goal programming (WGP) (Tamiz *et al.*, 1998). It is a pragmatic and flexible methodology for resolving multiple criteria decision making problems what ration formulation definitely is. Its advantage is also in familiarity with LP, since simplex algorithm is utilized to find the solution (Rehman and Romero, 1993).

The aim of this paper is to present developed spreadsheet tool, utilizing mathematical modelling techniques. In the first part a brief overview of WGP and penalty function is given. It is followed by a short description of the optimization tool. Then, the basic characteristics of the analysed case are presented, followed by the results and discussion. Brief conclusions are given in the last section.

MATERIAL AND METHODS

Weighted goal programming with penalty function

Weighted goal programming's formulation is expressed as mathematical model with a single objective (achievement) function (weighted sum of the deviations variables). Hence, the objective function in WGP model minimizes the undesirable deviations from the target goal levels and does not minimize or maximize goals themselves (Ferguson *et al.*, 2006). In most cases obtained solution is compromise between contradictory goals, enabled with positive and negative deviation variables. Negative deviation variables are included in the objective function for goals that are of type "more is better" and positive deviations variables are included in the objective function for goals of type "less is better". Since any deviation is undesired, the relative importance of each deviation variable is determined by belonging weights.

Since the goals are measured in different units and have different numerical values, the deviations are scaled with normalisation techniques (Tamiz *et al.*, 1998). With this process incommensurability is prevented and all deviations are expressed as ratio difference (i.e. (desired - actual)/desired) = (deviation)/desired)).

Rehman and Romero (1987) are pointing on the main drawback of WGP that is concerning the marginal changes. Namely, the method does not distinct between marginal changes within one observed goal; all changes (deviations) are of equal importance. This addresses another new issue in ration formulation example. Namely, in some situations too big deviation might lead to fail animal's requirements within nutrition desirable limits, and obtained solution is useless. To keep deviations within desired limits and to distinguish between different levels of deviations, penalty function (PF) might be introduced into the WGP model (Rehman and Romero, 1984).

Our approach enables one to define allowed positive and negative deviation intervals in more stages for each goal separately. Dependant on goal's characteristics (nature and importance of 100 % matching) these intervals might be different. Sensitivity is dependant on number and size of defined intervals and the penalty scale utilised (s_i; for i=1 to n). Penalty system is coupled with achievement function (WGP) through penalty coefficients.

Toll for two-phase beef ration formulation

The aim of the paper is to present a simple optimization tool for beef ration formulation, developed in MS Excel framework. It is designed as two phase approach (modules) based on mathematical programming techniques (LP and WGP with PF).

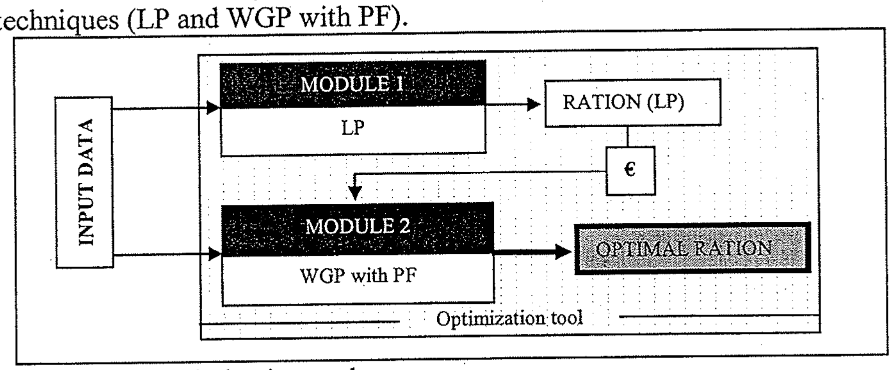

Figure 1: Scheme of the optimization tool

The first module (Figure 1) is based on LP paradigm and is an example of least-cost ration formulation. On the basis of the most important non-competitive constraints it searches for the roughly balanced ration at the least possible cost. On the solution obtained an estimate of cost magnitude expected might be made. Therefore the first module (LP) is as simple as possible (on constraints side), intended just to get crude cost estimation. Through cost function it is linked to the second module based on weighted goal program (WGP) with PF.

Mathematical formulation of the first and the second module

The first module (LP) is formulated as shown in equations (1), (4) and (7). It mostly relays on economic (cost) function (C) and satisfies only the most important nutrition requirements coefficients (b_i), known also as right hand side (RHS). In the first optimization phase one is searching for the ration at the lowest possible cost. Except minimum requirements (b_i) that should be met, prices (c_j) are the most important factor that dictates the level of jth feed (X_j) included into the ration.

$$\min C = \sum_{j=1}^{n} c_j * X_j \quad \text{such that} \tag{1}$$

$$\min Z = s_1 \sum_{i=1}^{k} w_i \frac{d_{i1}^- + d_{i1}^+}{g_i} + s_2 \sum_{i=1}^{k} w_i \frac{d_{i2}^- + d_{i2}^+}{g_i} \quad \text{such that} \tag{2}$$

$$\sum_{j=1}^{n} a_{ij} X_j + d_{i1}^- + d_{i2}^- - d_{i1}^+ - d_{i2}^+ = g_i \quad \text{for all } i = 1 \text{ to r and } g_i \neq 0 \tag{3}$$

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \quad \text{for all } i\text{=1 to m} \tag{4}$$

$$d_{i1}^- \leq g_i - p_{i1}^{\min} g_i \quad \text{for all } i\text{=1 to r} \tag{5a}$$

$$d_{i1}^- + d_{i2}^- \leq g_i - p_{i2}^{\min} g_i \quad \text{for all } i\text{=1 to r} \tag{5b}$$

$$d_{i1}^+ \leq p_{i1}^{\max} g_i - g_i \quad \text{for all } i\text{=1 to r} \tag{6a}$$

$$d_{i1}^{+} + d_{i2}^{+} \le p_{i2}^{max} g_i - g_i \qquad \text{for all } i\text{=1 do r} \qquad (6b)$$

$$d_{i1}^{+}, d_{i1}^{-}, d_{i2}^{+}, d_{i2}^{-}, X_j \ge 0 \qquad (7)$$

The second module (WGP with PF) is formulated as shown in equations (2) to (7). The achievement function (*Z*), expressed in equation (2) is defined as weighted sum of undesired deviation variables (d_{i1}^{+}, d_{i1}^{-}, d_{i2}^{+}, d_{i2}^{-}) from observed goals (g_i), multiplied with belonging penalty coefficients (s_1 and s_2). Obtained sum-product is subject of minimization (2). The relative importance of each goal is represented by weights (w_i) associated with the corresponding positive or negative deviations. To control deviations (5a, 5b, 6a, 6b) for each goal in WGP, penalty intervals (p_{i1}^{min}, p_{i1}^{max}, p_{i2}^{min}, p_{i2}^{max}) are in place. Because of the normalization process, only goals that have nonzero target values (3) could be relaxed with positive and negative deviations.

Obtained target value (*C*) in the first module enters into the second module (WGP with PF) as cost goal (3) that should be met as close as possible. This is also the only case where negative deviation is not penalised and also not restricted with intervals. All other constraints that do not have defined target value or do not have priority attribute are considered in equation (4). One of the main assumptions of the LP paradigm is also non-negativity that is considered for both models in equation (7).

Case analysis

The tool has been tested on a hypothetical case. It was presumed that beef fattening starts at 200 kg of live weight and stops at 600 kg. For the reason of more precise ration formulation, whole fattening period has been split into four breeding periods (100 kg weight gains) with different average daily gains. In the first period bulls gained 0.9 kg per day, while in the second and the third period the average daily weight gain is the same (1.1 kg). The last quarter last 100 day which means that average daily weight gain was 1 kg.

Table 1: Nutrition requirements divided into four breeding periods, presented as constraints (LP) and set of goals in WGP

		Fattening period							
		200-300 kg		300-400 kg		400-500 kg		500-600 kg	
		LP	WGP I / II	LP	WGP I / II	LP	WGP I / II	LP	WGP I / II
ME	(MJ)	>6,311	6,311	>6,574	6,574	>7,547	7,547	>9,105	9,105
MP	(g)	>46,880	46,880	>45,228	45,228	>48,114	48,114	>54,260	54,260
DM	(kg)	<632	632	<718	718	<920	920	<936	936
CF min	(kg)	>114		>129		>166		>168	
CF max	(kg)	<164		<187		<239		<243	
Ca	(g)	>4,152	4,152	>4,368	4,368	>4,462	4,462	>5,200	5,200
P	(g)	>2,358	2,358	>2,596	2,596	>2,958	2,958	>3,300	3,300
Price	(cent)		*C1*		*C2*		*C3*		*C4*
Hay	(kg/day)	<2		<2		<2		<2	

LP – constraints for the first module (both scenarios)
WGP I / II – constraints for the second module (both scenarios)

All nutritional requirements have been assessed with the spreadsheet model for ruminants' nutritional requirements estimation (Žgajnar *et al.*, 2007). The most important constraints and goals are presented in Table 1. Basic set of constraints in both modules (LP and WGP with PF) is more or less the same; they differ only in mathematical sign when they are transformed into goals.

In the process of ration formulation one should also consider other 'non-nutrition' constraints. In our hypothetical case study we assume quite frequent example that might be met on Slovene beef farms. Because of our climate characteristics, the first or second grass mowing is usually conserved as hay and from rest the grass silages are prepared. This is why the amount of hay in the diet is restricted and in all four periods maximal amount of hay is set to 2 kg per day (Table 1).

Initial version of WGP model involves six goals (Table 2). Importance of each goal is defined with weights (w_i) ranging between 0 and 100. For energy and protein requirements deviation intervals are very restricted, while for the rest of the goals deviations are more relaxed. For the dry matter intake that presents consumption capacity deviation intervals are defined only for underachievement of the goal, while overachievement is for practical reasons (consumption capacity) not allowed.

Table 2: Weights of defined goals and penalty function intervals for two scenarios

Goal		Penalty function intervals								Goal weights (w_i)
		Interval 1				Interval 2				
		p_{i1}^-		p_{i1}^+		p_{i2}^-		p_{i2}^+		
	Unit/scenario	SI	SII	SI	SII	SI	SII	SI	SII	
ME	(MJ)	1%		1%		5%		10%		70
MP	(g)	1%		1%		5%		10%		100
DM	(kg)	2%		0%		20%		0%		33
Ca and P	(g)	2%		5%		20%		30%		5
Price	(cent)	∞		4%	10%	∞		10%	15%	90

SI/ SII – first/ second scenario

p_{i1}^-, p_{i1}^+, p_{i2}^-, p_{i2}^+ - penalty intervals at the first and the second stage

Mineral appropriateness of the ration (preventing deficits as also toxic concentration) is assured through several safety nets (classical minimal and maximal constraints). This is also the reason why only two minerals (Ca and P) are considered as goals. Besides, their ratio should range between (1.1-1.5):1 in both modules to obtain solution. Applied approach of WGP with PF has been tested with varying extensions of cost deviation intervals (PF), which manifests in two scenarios (Table 2). In the first scenario price of obtained ration (WGP I) might deviate from set target value for the most 4 % to be penalised within the first stage (s_1) and at maximum 10 % within the second stage (s_2). In the second scenario (WGP II) both margins are relaxed (10 % and 15 %), while the penalty coefficients remain the same (s_1=1 and s_2=5).

In analyzed hypothetical case seven different feed (Table 3) and four different mineral-vitamin components were on disposal.

Table 3: Nutritive value of assumed feed

	DM	ME	MP	CF	Ca	P	Mg	Na	K	Price or FC*
	(g/kg)	(MJ/kg DM)	(g/kg DM)							(cent/kg)
Feed on disposal										
Hay	860	9.93	85.00	270	5.70	3.50	2.00	0.35	18.25	15.30
Maize silage	320	10.76	45.00	200	7.06	6.00	1.91	0.12	10.76	3.70
Grass silage	350	9.50	62.00	260	6.00	3.51	2.20	0.35	21.30	6.14
Grain maize	880	13.42	83.00	0.00	0.23	4.09	1.25	0.23	3.75	30.00
Wheat	880	13.47	88.00	0.00	0.57	3.86	1.59	0.45	5.00	32.00
Rapeseed cake	900	12.31	125.00	0.00	2.89	7.00	2.78	2.22	10.00	37.00
Soya meal	880	13.19	215.00	0.00	3.41	7.84	2.61	1.14	20.00	46.00

**Full cost approach*

We assumed that all forage (hay, grass silage and maize silage) is prepared on the farm. Since these forages are usually not tradable, we estimate full cost of their production on the basis of 'model calculations' prepared by Agricultural institute of Slovenia (KIS, 2007). All other forage on disposal could be purchased at market prices (Table 3).

RESULTS AND DISCUSSION

A hypothetical case has been chosen to test developed spreadsheet tool. Formulated rations for all four fattening periods are presented in Table 4. Between three analysed cases (LP, WGP I and WGP II) there is a significant difference in formulated rations, but in all three cases they are quite simple. The major differences occur as result of allowed deviations in WGP with PF compared to LP and because of the changes in penalty intervals between both WGP analyses (scenario I and II). The difference manifests in quantities of maize silage, grass silage and soya meal, dependant on economic parameters, while the hay quantities are the same in all three cases and are at the highest level allowed (2 kg/day).

From obtained results it is obvious that soya meal and grass silage are substitutes for proteins. It is interesting that soya meal is included in the ration when prices are more important (LP and WGP I). With regard to Slovene circumstances one would expect the opposite situation. This fact could be explained with 'economies of scale' where costs for home produced forage (grass silage) are mostly dependant on tillage and quantity of yields. Due to high importance of cost goal (Scenario 1), deviations never exceed defined goals that much to be in the second interval of overachievement, nor in the second scenario where intervals are extended. This is not the case in other goals (dry matter intake, Ca and P), where also the second (s_2) penalty interval operates.

From nutrition quality aspect we can conclude that WGP supported by PF yields more balanced ration as LP. These confirm also absolute sums of total relative deviations from nutritional requirements (as one of those parameters that measure the 'quality' of obtained results). This is significantly manifested in the second and third fattening period (WGP I and especially WGP II), where penalty system reduces energy surpluses. Even though WGP I rations are more balanced in all four breeding periods, they are for only 4 % more expensive as least-cost ration (LP). This fact is emphasised in the second scenario, where intervals for cost deviation are relaxed. As result they increase in comparison to the first scenario for 0.6 to 3.2 %, but total deviations (as quality parameter) improve for 0.6 up to 9.8 %, respectively. This could be understood as contradiction between nutrition quality and economics. However, when rations are not balanced - even if individual parameter requirements are fulfilled - one can not expect to achieve anticipated daily gains, resulting in higher per unit production costs.

Table 4: Obtained results and daily rations formulated with spreadsheet tool and cost penalty function scenarios

	Fattening period (daily ration)												Whole period (394 days) 200-600 kg		
	200-300 kg			300-400 kg			400-500 kg			500-600 kg					
	LP	WGP I	WGP II	LP	WGP I	WGP II	LP	WGP I	WGP II	LP	WGP I	WGP II	LP	WGP I	WGP II
Duration (days)	112			91			91			100			394		
Feed used (kg/day)															
Hay	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	788	788	788
Maize silage	8.81	4.05	3.99	14.93	7.06	4.14	21.17	9.04	6.31	19.39	13.17	10.68	6,211	3,237	2,465
Grass silage		6.18	6.20		8.31	11.92		9.91	13.15		8.61	11.18	0	3,211	4,093
Soya meal	0.77	0.41	0.43	0.72	0.34	0.17	0.41	0.17	0.03	0.62	0.08		251	100	66
Mineral components used (g/day)															
Limestone	13.28	8.29	8.50	6.05	9.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2,038	1,831	952
Bovisal	0.00	0.00	0.00	0.00	0.00	1.59	0.00	0.00	0.00	0.00	0.00	0.00	0	0	145
Salt	15.3	20.9	20.9	20.1	26.7	29.5	24.5	30.5	33.4	23.5	31.5	33.6	8,132	10,700	11,423
Price (cent/day)	99.6	103.5	104.2	120.0	124.8	128.6	129.0	134.2	137.9	145.1	150.9	154.3			
Price (EUR/period)	111.5	116.0	116.7	109.2	113.5	117.0	117.4	122.1	125.5	132.0	137.3	140.4	470.12	488.92	499.60
Requirements deviations (%)															
ME	0.0	0.0	0.0	6.4	1.0	1.0	14.3	0.2	0.0	0.0	1.0	0.0			
MP	0.0	-0.6	0.0	0.0	-1.0	0.0	0.0	-1.0	0.0	0.0	-1.0	0.0			
DM	-7.1	-1.3	-1.4	-9.3	-8.5	-6.2	-12.2	-18.3	-16.9	-9.3	-3.4	-2.9			
Ca	0.0	-2.0	-2.0	0.0	0.0	-6.4	20.1	5.1	5.6	6.7	11.3	10.4			
P	34.2	15.0	15.0	39.0	12.6	5.0	52.3	13.0	6.2	44.0	28.5	22.0			
Total deviation	41.2	19.0	18.4	54.6	23.1	18.6	98.8	37.6	28.7	60.0	45.2	35.4			
Price deviation (%)	0.0	4.0	4.6	0.0	4.0	7.2	0.0	4.0	6.9	0.0	4.0	6.4			
Ratio between minerals															
Ca:P	1.3	1.5	1.5	1.2	1.5	1.5	1.2	1.4	1.5	1.2	1.4	1.4			
Physical ration attribute															
CF (kg/day)	1.03	1.29	1.28	1.42	1.67	1.81	1.82	1.94	2.06	1.87	2.30	2.38			
CF (%)	20	23	23	20	23	25	20	24	25	20	23	24			
DM (kg/day)	5.2	5.6	5.6	7.2	7.2	7.4	8.9	8.3	8.4	9.3	9.9	10.0			

LP – solution obtained by the first module
WGP I – solution obtained by the second module, first scenario
WGP II – solution obtained by the second module, second scenario

CONCLUSIONS

From the results obtained it is apparent that combination of deterministic linear programming technique and weighted goal programming supported by penalty function is useful approach, especially if this is the 'engine' from user-friendly optimization tool. Namely, it enables one to formulate least-cost ration not taking to much risk of worsening the ration's nutritive value that is the main drawback of LP.

Refined control is possible through penalty function system that differs between different deviation sizes for each goal separately. This is becoming more and more important in nutrition management.

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Three phase feed-mix optimization for growing pigs

Abstract

The ability to be adaptable in the process of daily ration formulation demands handy tools to support their calculation. This paper presents an example of such a tool, which is based on a three phase optimization approach. In the first phase, a common linear program is utilized to formulate rations on a least-cost basis. In the second stage, a sub-model, which is based on weighted goal programming and supported by a system of penalty functions, is used to formulate a nutritionally balanced and economically acceptable ration. This ration relies upon the ration cost calculated in the first phase. In the last stage, the tool runs the first and the second phases several times with the intent of finding the most "efficient" energy content of the ration. The obtained results confirm the benefits of the applied approach. This model enables decision makers to find the optimal energy content of the pigs' diets, which changes frequently due to rapidly fluctuated economic circumstances.

Introduction

Pork production is globally characterized by low profits, demanding adaptable management, and adjustable production. Because the farmer's main objective is to maximize profits, costs must be minimized. This may be accomplished through improved technical or economical efficiency. Because of the high expense of ration costs and the possibility of negative externalities that might occur, it is obvious that ration formulation is a crucial task in daily pig breeding management.

Pig production is also one of those agricultural activities that are not necessary connected with arable land. This sector is therefore closely related to common industrial production. In particular, the majority of inputs may be exogenous, or not produced on the farm. In this case, changes in world (cereal) markets could rapidly affect the economic outcome. However, even if the majority of the feed is produced at the farm gate, there are opportunity costs that require the decision maker to make efficient decisions in relation to breeding practices. This may allow for improved productivity, or at least may keep profitability at an acceptable level. Because of rapid changes in exogenous factors and simultaneous technological improvements, this task is becoming more and more challenging. In order to help breeders to deal with these challenges, many tools based on constraint optimization have been developed.

Pioneering work in this area has been conducted by Waugh (1951), who applied the linear programming (LP) paradigm in order to formulate rations on a least-cost basis. This approach has been very popular in the past, especially after the rapid development of personal computers. In the 1960s, it became a classical approach to formulate animal diets as well as feed-mixes (Black and Hlubik, 1980). More recently, Castrodeza et al. (2005) stressed that the daily routine of ration formulation is one of the fields in which LP is most widely used.

Common to all LP problems is the concept of constraint optimization, which means that one tries to find the optimum of a single objective function. However, exclusive reliance just on one objective (cost function) as the only and the most important decision criteria is one of the reasons why the LP paradigm may be a deficient method in the process of ration formulation (Rehman and Romero, 1984; 1987). Lara and Romero (1994) stress that in practice, decision makers never formulate rations exclusively on the basis of a single objective, but rather on the basis of several different objectives, where economic issues are only one of many concerns.

In common LP models for pig ration formulation, animal amino acid requirements are usually expressed in terms of minimal concentrations. Such models do not consider the total exceeded amount of protein or its quality as long as the minimal amounts of essential amino acids are satisfied (Bailleul et al., 2001). The same authors stress that "economical optimal" diets are often too rich in protein, which directly burdens the environment and does not improve animal growth. This problem could partly be solved by adding additional upper or lower constraints. However, it might rapidly lead into over-constraint model that has no feasible solution. This problem is also related to the next LP drawback. It is mathematical rigidity of constraints (right hand side – RHS), which might also result in facts with no solution (Rehman and Romero, 1984). This means that no constraint (e.g. given nutrition requirements) violation is allowed at all. However, relatively small deviations in RHS would not seriously affect animal welfare, but would result in a feasible solution (Lara and Romero, 1994).

Numerous methodological developments in the field of mathematical programming (MP) have eased these problems of LP paradigm (Buysse et al., 2007). For instance in the field of animal nutrition, Rehman and Romero (1984) introduced goal programming and its improvement with a system of penalty function, as well as multi-objective programming (MOP) as a way to incorporate more than one objective function; Lara and Romero (1994) applied interactive methodologies where the optimal ration is achieved through "computer dialog"; Castrodeza et al. (2005) addressed a multicriteria fractional model.

The purpose of this paper is to present a tool for pig ration formulation, designed as a three-phase optimization approach that merges two normative mathematical programming techniques. The first part of the paper provides a brief overview of weighted goal programming (WGP) and the penalty function. This is followed by a short description of the optimization tool that also involves LP in order to calculate least-cost ration formulation. Finally, the characteristics of the analysed case are presented, followed by the results and discussion.

Material and methods

Weighted goal programming supported by a system of penalty functions

Based on the approaches reported in the literature and the primary aim of this tool, we decided to apply the WGP approach. This was in the context of ration formulation introduced by Rehman and Romero (1984). The WGP approach is a pragmatic and flexible methodology for resolving multiple criteria decision making problems. In this case, a farmer is interested in an economically efficient ration that achieves a balance between several conflicting objectives that include cost, nutrition imbalances, and possible negative impacts on the environment (Weintraub et al., 2001).

WGP formulation is expressed as a mathematical model with a single objective (achievement) function (the weighted sum of the deviations variables). The optimal compromise solution is found through the philosophy of "distance measure" that measures the deviation between the desired goal and the performance level of a goal.

In most cases, the obtained solution is a compromise between contradictory goals, enabled with positive and negative deviation variables. Negative deviation variables are included in the objective function for goals that are of the "more is better" type, and vice versa. Relative importance of each deviation variable is determined by belonging weights.

Since the goals are measured in different units and have different numerical values, the deviations are scaled with normalization techniques (Tamiz et al., 1998). Through this process, incommensurability is prevented and all deviations are expressed as ratio differences.

Rehman and Romero (1987) point out that the main drawback of WGP concerns marginal changes. Namely, the method does not distinguish between marginal changes within one observed goal; all changes (deviations) are of equal importance. This addresses an additional issue that relates to the example of ration formulation. Specifically, in some situations, too large of a deviation might result in a failure to keep the animal's diet within desirable nutritional limits, rendering the solution useless. To keep deviations within desired limits and to distinguish between different levels of deviations, a system of penalty functions (PF) needs to be introduced into the WGP model (Rehman and Romero, 1984).

This system is coupled with the achievement function (WGP) through penalty coefficients and with additional constraints defining deviation intervals. This approach enables one to define allowable positive and negative deviation intervals separately for each goal. Depending on the goal's characteristics (nature and importance of 100 % matching), these intervals might be different. Sensitivity is dependent on the number and size of defined intervals and the penalty scale utilized (s_i; for i=1 to n).

Tool for three phase pig ration formulation

This optimization tool for pig ration formulation was developed in MS Excel as an add-in application. This tool is capable of formulating least-cost, nutritionally balanced, and environmental acceptable rations for growing pigs in different production periods. It also gives information about which feed-mix provides the optimal energy content.

The tool is organized as a three phase approach that merges two sub-models based on mathematical programming techniques (Figure 1). The first sub-model is an example of a common least-cost ration formulation, based on the LP paradigm. The purpose of including this into the tool is to get an approximate estimate of expected ration cost. In this manner, the tool calculates the target economic goal, which is one of the goals in the second sub-model. The first sub-model is therefore, from the perspective of constraints, as simple as possible and is intended to exclusively measure the crude cost estimation. Through cost function, this is linked to the second sub-model. The latter is based on WGP and is supported by a system of six sided PF. In this approach, the desired nutrition levels and ration costs are modelled as goals instead of as constraints. In the second sub-model, additional constraints with indirect influence on the environment are added. Consequentially, the model is much more complex, and it finally yields a better solution-formulated ration.

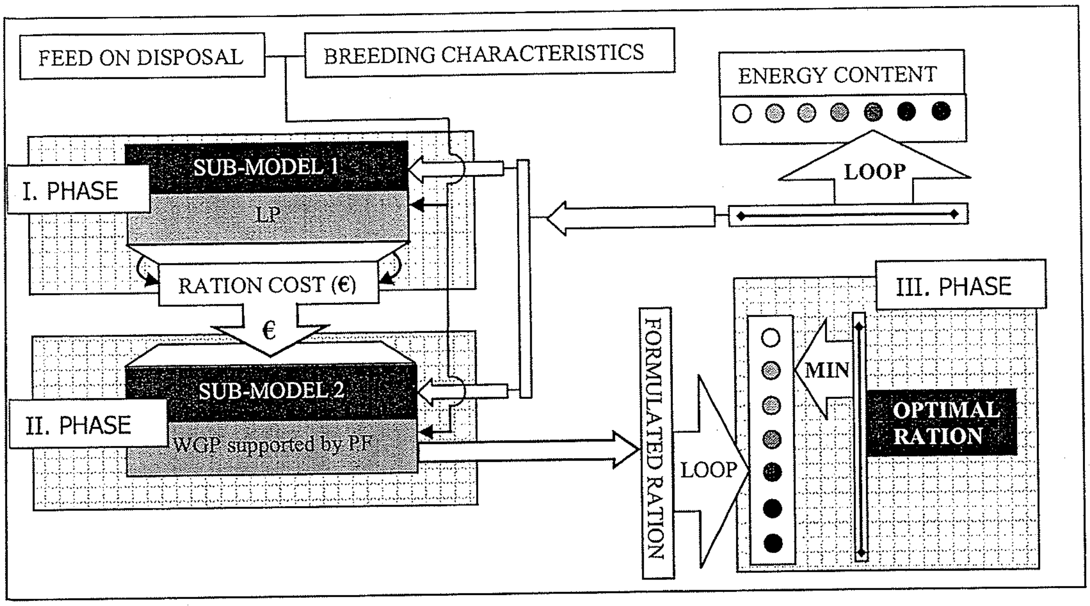

Figure 1: The scheme of the tool for three phase pig ration formulation

Because of the importance of the energy concentration of the feed-mix and its influence on the ration structure and cost, the tool also includes a third phase. In this phase, a macro loop is added that runs the first and the second sub-models for n-times, and consequentially it yields n-formulated rations. The number of iterations in the third phase depends on the starting/ending energy content of the feed-mix and on the energy rise in each iteration step (e.g. 0,1 MJ/kg). From the n-obtained solutions, the tool selects the cheapest option and marks it as the "optimal" feed-mix structure for this given example.

Mathematical formulation of the first and the second sub-model

The first sub-model (LP) is formulated as shown in equations (1*), (4a), and (7). It mostly relies on economic (cost) function (C) and satisfies only the most important nutrition requirements coefficients (b_i), known also as RHS. In the first optimization phase, one is searching for the ration at the lowest possible cost (C).

$$\min C = \sum_{j=1}^{n} c_j * X_j \qquad \text{such that} \qquad (1^*)$$

$$\min Z = s_1 \sum_{i=1}^{k} w_i \frac{d_{i1}^- + d_{i1}^+}{g_i} + s_2 \sum_{i=1}^{k} w_i \frac{d_{i2}^- + d_{i2}^+}{g_i} \qquad \text{such that} \qquad (2)$$

$$\sum_{j=1}^{n} a_{ij} X_j + d_{i1}^- + d_{i2}^- - d_{i1}^+ - d_{i2}^+ = g_i \qquad \text{for all } i = 1 \text{ to r and } g_i \neq 0 \qquad (3)$$

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \qquad \text{for all } i=1 \text{ to m} \qquad (4a)$$

$$\sum_{j=1}^{n} \left(a_{ij} - (R^{\%}) a_{kj}\right) X_j \leq 0 \qquad \text{for all } i=1 \text{ to m} \quad \text{and } i \neq k \qquad (4b)$$

$$d_{i1}^{-} \leq g_i - p_{i1}^{\min} g_i \qquad \text{for all } i=1 \text{ to r} \qquad (5a)$$

$$d_{i1}^{-} + d_{i2}^{-} \leq g_i - p_{i2}^{\min} g_i \qquad \text{for all } i=1 \text{ to r} \qquad (5b)$$

$$d_{i1}^{+} \leq p_{i1}^{\max} g_i - g_i \qquad \text{for all } i=1 \text{ to r} \qquad (6a)$$

$$d_{i1}^{+} + d_{i2}^{+} \leq p_{i2}^{\max} g_i - g_i \qquad \text{for all } i=1 \text{ do r} \qquad (6b)$$

$$d_{i1}^{+}, d_{i1}^{-}, d_{i2}^{+}, d_{i2}^{-}, X_j \geq 0 \qquad (7)$$

The second sub-model (WGP with a PF) is formulated as shown in equations (2) to (7). The achievement function (Z), expressed in equation (2), is defined as the weighted sum of the undesired deviation variables (d_{i1}^{+}, d_{i1}^{-}, d_{i2}^{+}, d_{i2}^{-}) from observed goals (g_i), multiplied by belonging penalty coefficients (s_1 and s_2) that measure the slope of the penalty function. The obtained sum-product is the subject of minimization (2). The relative importance of each goal is represented by weights (w_i) associated with the corresponding positive or negative deviations. Penalty intervals (p_{i1}^{min}, p_{i1}^{max}, p_{i2}^{min}, p_{i2}^{max}) are in place to prevent uncontrolled deviations (5a to 6b) within each goal. Because of the normalization process, only goals that have nonzero target values (3) could be relaxed with positive and negative deviations. The obtained target value (C) in the first sub-model enters into the second one (WGP with PF) through "cost goal" ($g_i = C$). This is also the only case where negative deviation is not penalized and also not restricted to intervals. All other constraints that do not have defined target values or do not have priority attributes are considered in the equation (4a). All upper bounds for ratios ($R^{\%}$) are transformed into linear equations with equation (4b), and the same holds for lower bounds, which should be multiplied by -1. Non-negativity condition for both models is considered in equation (7).

Analyzed example

To illustrate the use of the tool, we chose a hypothetical case of pig production. We considered that the tool should formulate the complete ration/feed-mix in relation to the nutritional requirements. Due to significant changes in nutritional requirements throughout a pig's life, the fattening period (40 kg – 100 kg) has been split into three periods with a 20 kg weight gain in each. In each period, the average daily weight gains were different. In the first period, the pigs gained 740 g/day; in the second period, they gained 800 g/day; in the last period, they gained 750 g/day.

Table 1: Assumed daily requirements for three fattening periods

		Fattening period		
		40-60 kg	60-80 kg	80-100 kg
Average daily weight gain (g/day)		740	800	750
Metabolisable energy (ME)	MJ	25.5	31.4	34.8
Crude protein (CP)	g/day	330	370	340
Lysine (Lys)	g/day	17.2	19.5	18.8
Methionine + Cystine (Met + Cys)	g/day	10.3	11.7	11.3
Methionine (Met)	g/day	5.2	5.9	5.6
Threonine (Thr)	g/day	10.3	11.7	11.3
Tryptophan (Trp)	g/day	3.4	3.9	3.8

All nutrition requirements are taken from DLG (1991). The most important are presented in Table 1. Besides those, the tool also considers the mineral requirements (Ca, P, and Na). The formulated ration should also have the appropriate crude fibre content, which is assured through minimal and maximal ratio as well as protein digestibility. In order to prevent a solution that has too much of one feed in the diet, we considered recommendations for maximal feed inclusion (Futtermittelspecifische ..., 2006).

Table 2: Importance of goals with corresponding penalty function intervals

			Penalty function intervals				Together	
		Weight	p_{i1}^+	p_{i1}^-	p_{i2}^+	p_{i2}^-	p_i^+	p_i^-
Goal	Unit (/day)	(w_i)	%				%	
ME	MJ	80	1	0	2	0	3	0
CP	g	65	1	0	2	0	3	0
Lys	g	75	2	1	3	3	5	4
Met + Cys, Met, Thr and Trp	g	65	3	2	5	4	8	6
P_{digest}	g	20	5	5	10	10	15	15
Cost	Cent	20/90	5	∞	20	∞	25	∞

Weights indicate the decision maker's preferences with respect to each goal. The tool offers the option to switch between goals and constraints, depending on the needs of the decision maker. In the analyzed case, we chose nine goals (Table 2) that should be met as accurately as possible. The importance of each goal is defined by weights (w_i) ranging between 0 and 100. For each goal, deviation intervals are defined separately. They are measured in percentage deviation from the desired level. The most rigorous and short intervals are anticipated by energy, protein, and amino acids goals. Specifically, reducing the unbalanced protein fraction by increasing protein quality (fulfilling the amino acids ratios in relation to the energy) reduces nitrogen excretion and pollution.

The tool also includes "the library" of feeds and their nutrition values. It is organized in such a way that it is possible to change the quality parameters, as well as add new ones. The initial tool version includes 35 feeds and vitamin-mineral mixtures. In the process of ration formulation, one can select only those that are at one's disposal to enter into the formulated ration.

Results

The application of the tool is presented through a simple example that might be applicable to larger agricultural holdings. This means that rations primarily consist of feed-mixes prepared at the farm gate. We have presumed that the decision maker prepares three different feed-mixes for growing pigs, in two different scenarios. In the first scenario, the most important element is quality of the ration ($W_{cost}=20$), while in the second scenario, cost is more important ($W_{cost}=90$).

The results obtained are presented in Figures 2 and 3. Figure 2 illustrates the structure of two different ration sets differentiated by their cost importance. Within each set, formulated rations are dependent on the energy concentration of animal rations. The range of the energy content of the ration was set between 12.3 and 13.7 MJ ME. Figure 3 illustrates the level of ration costs for different fattening periods over the same range of ME content.

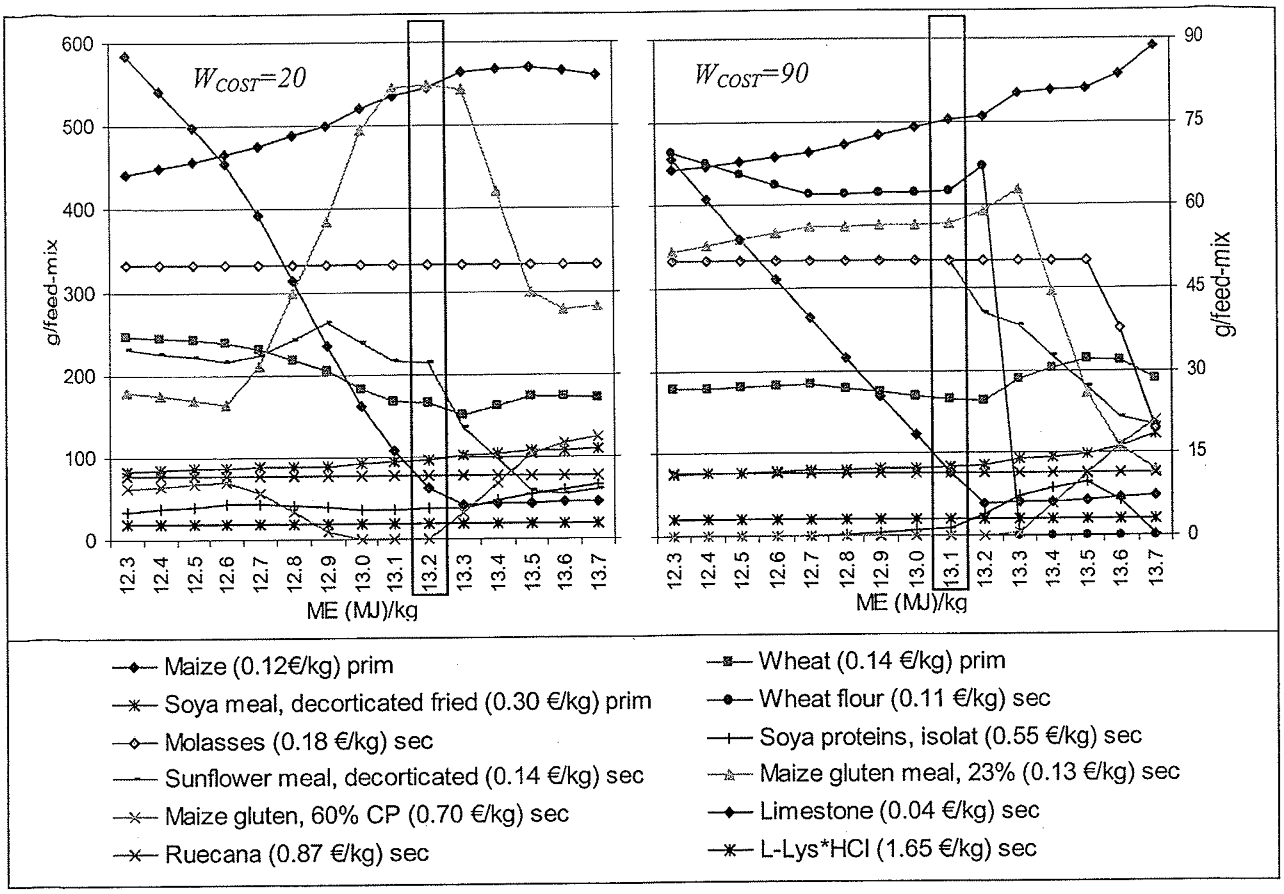

Figure 2: Formulated feed-mix for the second fattening period at low (W=20) and high importance (W=90) of ration cost (prim = primary axis; sec = secondary axis)

One of the main parameters that defines how much a pig is going to eat is the energy content of the feed-mix. If the feed-mix is more concentrated, an animal is going to eat less, and vice versa. Figure 2 presents formulated rations for the second fattening period. It is obvious that the energy content of the ration strongly influences selection of the feed. With increasing energy content, the quantity of maize increases and the quantity of wheat decreases. From Figure 2, it is apparent that cheap wheat flour reduces costs, since it enters into the solution only at high *W* values. The same holds for sunflower meal. From Figure 2, one can also observe the phenomena of energy-low rations, demonstrated by high limestone content.

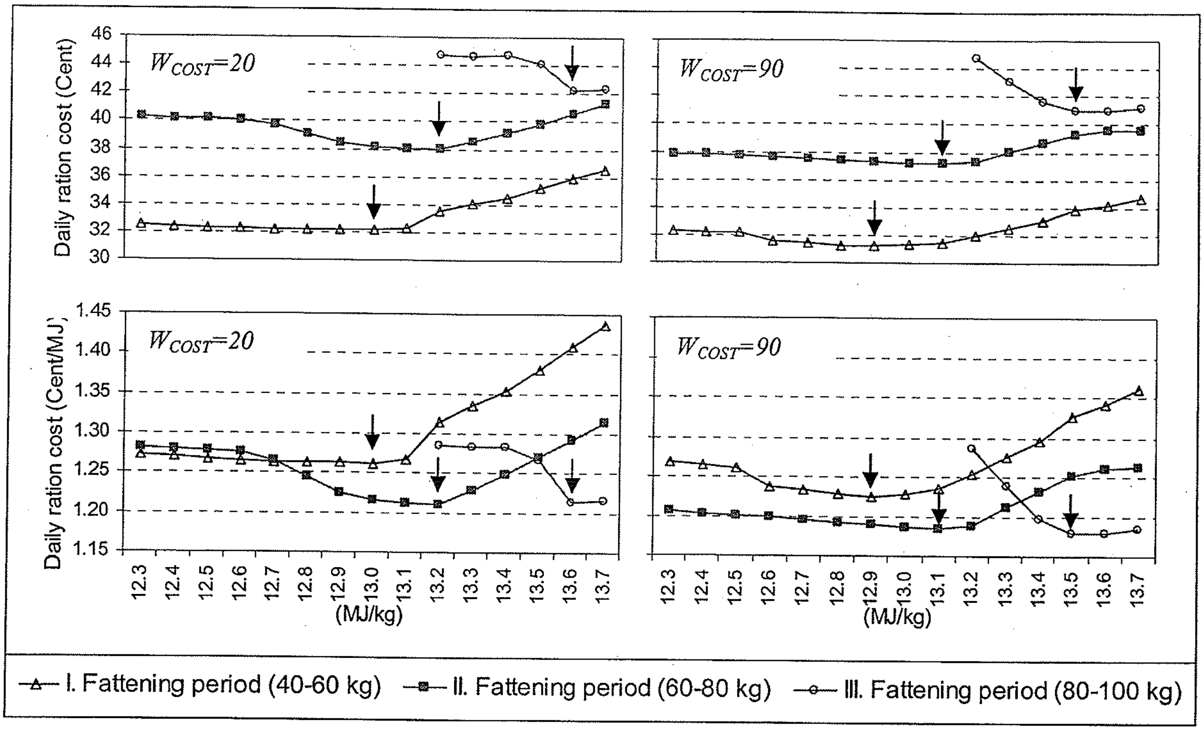

Figure 3: Daily ration costs dependent on energy content of the feed-mix by low (left side) and high (right side) ration cost importance

The importance of finding the "optimal" energy content of the feed-mix, which further influences its structure and the profitability of pork production, is illustrated in Figure 3. It is logical that pressure on economics reduces rations' cost. The difference ranges between a few tenths of a cent up to several cents per day, and increases with animal growth. Of course, the difference for one pig per day is no big deal, but if one considers a facility with 50,000 animals, this becomes an important issue. It is an interesting coincidence that optimal rations in all three fattening periods shift to the left if the cost is of higher importance. Even though the difference is only 0.1 MJ, this demonstrates that it is cheaper to formulate feed-mixes with lower energy content. From Figure 3 it is also apparent that in spite of lower daily ration cost in earlier fattening periods, such rations are more expensive per MJ of ME.

With animal growth, the optimal energy content shifts to higher concentrations. From Figure 3, we can see that in the third fattening period, the tool finds solution only from 13.2 MJ onwards. Deviations from set goals are too big and the tool does not find solutions at lower energy.

The difference in ration costs between different energy concentrations is obvious. It ranges 2.4 up to 4.5 cents per daily ration. In any case, it should be an important issue to find the "optimal" energy concentration in the daily management of pork production.

Conclusions

The results of this study show that the three phase optimization approach, supported by mathematical programming (LP and WGP with PF), can be applied efficiently to the ration formulation for growing pigs. Through using this tool, more efficient diets might be formulated, since the model enables the decision maker to find the optimal energy content of the diet for various economic circumstances. The tool could be utilized in medium and large-scale agricultural holdings, which are usually the major pollutants of the environment, and where such tasks are an important part of daily management. Specifically, precisely balanced rations prevents over-feeding as well as under-feeding, both of which are expensive and burden the environment.

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Multi-goal pig ration formulation; mathematical optimization approach

J. Žgajnar[1] and S. Kavčič[2]

[1]University of Ljubljana, Biotechnical Faculty, Deptartment of Animal Science, Groblje 3, SI-1230 Domžale, Slovenia; e-mail: jaka.zgajnar@bfro.uni-lj.si
[2]The same address as [1]

Abstract. Organically produced pork is characterized by high production costs, within the main part goes to ration cost. Forage must be produced under strict conditions, reflecting in high prime costs. The main challenge for farmers is how to formulate economically efficient, nutrition balanced and politically acceptable rations at the least-cost to be competitive. This challenging task demands handy tool that merges all three viewpoints. In this paper an example of such a tool, based on three step approach, is presented. In the first step, a common linear program is utilized to formulate least-cost ration. In the second step, a sub-model, based on weighted goal programming and supported by a system of penalty functions, is used to formulate a nutritionally balanced and economically acceptable ration that also fulfils conditions demanded by organic farming. The most 'efficient' energy content of the ration is searched in the last step. The obtained results confirm the benefits of the applied approach.

Key words: mathematical programming, ration costs, organic farming, pork

INTRODUCTION

Organic farming is globally characterized by higher production costs that are affected by strict organic production policy constraints; however profits are very diverse and are highly related to the market strategy in place. Because the farmer's main objective is to maximize profits, costs must be minimized. This may be accomplished through improved technical or economical efficiency. Due to high expense of ration costs and the possibility of negative externalities that might occur, it is obvious that ration formulation is a crucial task in daily pig breeding management– even more if the organic farming practice is in place.

Comparing to the conventional production the majority of fodder is usually produced at the farm gate or less common, purchased (maximum 20%) from another organic producer in the same region at the relatively high price. In this case, changes in world (cereal) markets could rapidly affect the economic outcome. However, even if the majority of the feed is produced at the farm gate, there are opportunity costs that require the decision maker to make efficient decisions in relation to breeding practices. This may allow for improved productivity, or at least may keep profitability at an acceptable level. Organic fattening confronts also with the lack of availability of pure amino acids that results in more unbalanced protein composition, increased feed cost and what is unlike with organic philosophy, increased load of excessive nitrogen from manure on the environment (Blair, 2007). In order to help breeders to deal with these challenges, many tools based on mathematical programming (MP) paradigm have been developed.

The first problem of this kind has been conducted by Waugh (1951), who applied the linear programming (LP) paradigm in order to formulate rations on a least-cost basis. This approach has been very popular in the past, especially after the rapid development of personal computers. In the 1960s, it became a classical approach to formulate animal diets as well as feed-mixes (Black & Hlubik, 1980). More recently, Castrodeza et al. (2005) stressed that the daily routine of ration formulation is one of the fields in which LP is most widely used.

Common to all LP problems is the concept of constraint optimization, which means that one tries to find the optimum of a single objective function. However, exclusive reliance just on one objective (cost function) as the only and the most important decision criteria is one of the reasons why the LP paradigm may be a deficient method in the process of ration formulation (Rehman & Romero, 1984; 1987). Lara & Romero (1994) stress that in practice decision makers never formulate rations exclusively on the basis of a single objective, but rather on the basis of several different objectives, where economic issues are only one of many concerns.

In common LP models for pig ration formulation, animal amino acid requirements are usually expressed in terms of minimal concentrations. Such models do not consider the total exceeded amount of protein or its quality as long as the minimal amounts of essential amino acids are satisfied (Bailleul et al., 2001). The same authors stress that 'economical optimal' diets are often too rich in protein, which directly burdens the environment and does not improve animal growth. This problem could partly be solved by adding additional upper or lower constraints. However, it might rapidly lead into over-constraint model that has no feasible solution. This problem is also related to the next LP drawback-rigidity of constraints (right hand side–RHS) (Rehman & Romero, 1984). This means that no constraint (e.g. given nutrition requirements) violation is allowed at all. However, relatively small deviations in RHS would not seriously affect animal welfare, but would result in a feasible solution (Lara & Romero, 1994).

Numerous methodological developments in the field of MP have eased these problems of LP paradigm (Buysse et al., 2007). For instance in the field of animal nutrition, Rehman & Romero (1984) introduced goal programming (GP) and its improvement with a system of penalty function (PF), as well as multi-objective programming (MOP) as a way to incorporate more than one objective function; Lara & Romero (1994) applied interactive methodologies where the optimal ration is achieved through 'computer dialog'; Castrodeza et al. (2005) addressed a multicriteria fractional model.

The purpose of this paper is to present a spreadsheet tool for organic pig ration formulation, designed as a three-phase optimization approach that merges two normative MP techniques. The first part of the paper provides a brief overview of weighted goal programming (WGP) and the penalty function. This is followed by a short description of the optimization tool that also involves LP in order to calculate least-cost ration formulation. Finally, the characteristics of the analysed case are presented, followed by the results and discussion.

MATERIALS AND METHODS

Weighted goal programming supported by a system of penalty functions

Common to all MP problems is the concept of constraint optimization, which means that one tries to find the optimum of a single objective function within set of constraints. Based on the approaches reported in the literature and the primary aim of the tool presented in this paper, we decided to apply the WGP approach. This was in the context of ration formulation introduced by Rehman & Romero (1984).

WGP formulation is expressed as a mathematical model with a single objective (achievement) function (the weighted sum of the deviations variables). The optimal compromise solution is found through the philosophy of 'distance measure' that measures the discrepancy between the desired goal and the performance level of a goal. To consider all goals simultaneously normalization techniques should be applied (Tamiz et al., 1998).

Rehman & Romero (1984) introduced PF paradigm into the WGP to keep deviations within desired limits and to distinguish between different levels of deviations. This system is coupled with the achievement function (WGP) through penalty coefficients and with additional constraints defining deviation intervals. Such approach enables one to define allowable positive and negative deviation intervals separately for each goal. Depending on the goal's characteristics (nature and importance of 100% matching), these intervals might be different. Sensitivity is dependent on the number and size of defined intervals and the penalty scale utilized (s_i; for i=1 to n).

Tool for three phase pig ration formulation

Presented optimization tool for organic pig ration formulation was developed in MS Excel as an add-in application. This tool is capable of formulating least-cost, nutritionally balanced, and environmental acceptable rations for 'organically' growing pigs in different production periods. It also gives information about which feed-mix provides the optimal energy content.

The tool is organized as a three phase approach that merges two sub-models based on MP techniques. The first sub-model is an example of a common least-cost ration formulation, based on the LP paradigm. The purpose of including this into the tool is to get an approximate estimate of expected ration cost. In this manner, the tool calculates the target economic goal, which is one of the goals in the second sub-model. The first sub-model is therefore, from the perspective of constraints, as simple as possible and is intended to exclusively measure the 'rough' cost estimation. Through cost function, this is linked to the second sub-model. The latter is based on WGP and is supported by a system of six sided PF. In this approach, the desired nutrition levels and ration costs are modelled as goals instead of as constraints. Besides in the second sub-model, additional constraints with indirect influence on the environment are added. Consequentially, the model is much more complex, and it finally yields a better solution. For more detailed mathematical description of the model one can refer to Žgajnar & Kavčič (2008), where the similar approach has been applied.

Due to the importance of energy concentration of the feed-mix and its influence on the ration structure and cost, the tool also includes a third phase. In this phase, a macro loop is added that runs the first and the second sub-models for n-times, and consequently it yields n-formulated rations. The number of iterations in the third phase depends on the starting/ending energy content of the feed-mix and on the energy rise in each iteration step (e.g. 0,1 MJ kg^{-1}). From the n-obtained solutions, the tool selects the cheapest option and marks it as the 'optimal' feed-mix structure for this given example.

Analyzed example

The tool has been applied for hypothetic organic pork production, with an average genotype for less intensive fattening. In this paper we present just the fattening period between 50 and 100 kg with an average daily gain of 700 g. We considered that the tool should formulate the complete ration/feed-mix in relation to the nutritional requirements. It is presumed that most of the fodder is produced at the farm under organic conditions and is evaluated with the full cost approach. The rest feed (less than 20%) that cannot be produced at the farm is accounted for at market price. However no synthetic substances (e.g. amino acids supplement) could be added, since they are banned by law.

The nutrition requirements (Metabolizable energy (35.2 MJ day^{-1}), Crude protein (399 g day^{-1}), Amino acids (Lys–19.7 g day^{-1}; Met+Cys–11.3 g day^{-1}; Thr–13 g day^{-1}; Trp–3.6 g day^{-1}) and Minerals (Ca–12.88 g day^{-1}; P–11.59 g day^{-1}; $P_{available}$–4.89 g day^{-1}; Na–2.58 g day^{-1})) are taken from Blair (2007). In order to prevent unrealistic solution that has too much of one feed in the diet, we considered recommendations for maximal feed inclusion (Blair, 2007) and (Futtermittelspecifische ..., 2006), namely through additional upper-bound constraints (Table 1). In the process of ration formulation the tool could choose between twelve different feeds (Table 1) that might be produced at the farm (except: alfalfa-dehydrated, yeast-brewer's dried, potato protein concentrate that might be purchased at market price), and four mineral components (limestone, salt, monocalcium phosphate and dicalcium phosphate) that could be purchased at market price.

Table 1. Prices and nutritive values of available feed and their suggested maximal share of the ration.

Feed on disposal	Price* (Cent kg^{-1})	ME MJ kg^{-1}	DM	CP	Lys	Met+ Cys	Thr	Trp	Max** %
			g kg^{-1}						
Maize	18	14.1	880	85	2.5	3.5	3.0	0.8	0.6
Wheat	21	13.8	880	120	3.4	4.5	3.5	1.5	0.7
Barley	21	12.6	880	106	3.8	3.7	3.7	1.4	-
Oats	26	11.2	880	108	4.3	4.1	3.7	1.4	0.25
Wheat flour	17	12.5	880	167	7.3	5.6	6.5	2.0	0.15
Wheat bran	14	8.3	880	141	6.2	5.0	5.5	2.5	0.25
Alfalfa, dehydrated	33	6.1	910	180	8.7	4.5	7.8	2.9	-
Yeast, brewer's dried	71	13.2	900	452	32.1	11.7	21.8	5.1	0.05
Potato protein concentrate	132	15.7	930	780	56.9	20.1	45.3	10.6	0.15
Lupinseed meal	58	14.1	890	349	15.4	7.8	12.0	2.6	0.15
Faba beans	42	12.7	870	254	16.2	5.2	8.9	2.2	0.2
Pea - field	38	13.4	890	228	15.0	5.2	7.8	1.9	0.3

**Prices are estimated with model calculations – own source*

*** Suggested maximum inclusion of feedstuffs in pig diets*

Table 2. Importance of goals with corresponding penalty function intervals.

Goal	Unit (day^{-1})	Weight (w_i)	p_{i1}^+	p_{i1}^-	p_{i2}^+	p_{i2}^-	p_i^+	p_i^-
			Penalty function intervals %				Together %	
ME	MJ	75	1	0	2	0	3	0
CP	g	60	1	0	2	0	3	0
Lys	g	80	5	1	5	3	10	4
Met + Cys	g	60	5	1	5	3	10	4
Thr and Trp	g	60	5	1	10	3	15	4
$P_{available}$	g	40	3	1	5	3	8	4
Ca and Na	g	30	3	1	5	3	8	4
Cost	cent	5/90	10	∞	20	∞	30	∞

p_{i1}^+, p_{i1}^-, p_{i2}^+, p_{i2}^- penalty intervals at the first and the second stage

The tool offers the option to switch between goals and constraints, depending on the needs and preferences of the decision maker. In the analyzed case, we chose ten goals (Table 2) that should be met as accurately as possible.

The importance of each goal is defined by weights (w_i) ranging between 0 and 100. Relatively high values are set for amino acids, since reduction of unbalanced protein fraction by increased protein quality (fulfilling the amino acids ratios in relation to the energy) reduces nitrogen excretion and pollution. For each goal, deviation intervals are defined separately (Table 2). They are measured in percentage deviation from the desired level. The cost goal is the only one that is not penalized for negative deviation and simultaneously the negative interval is unlimited.

RESULTS AND DISCUSSION

The main objective of the tool presented in this paper is to assist organic producers in formulating diets that are balanced and at the same time as cheap as possible. On a simple example we present how the tool could be applied and what might be the benefits. Namely, for organic producers this task is due to numerous limitations and constraints very complex. We have presumed that the decision maker prepares a feed-mix for growing pigs, looking from two different viewpoints (scenarios). In the first scenario, the most important element is quality of the ration ($W_{cost}=5$), while in the second one, cost is more important ($W_{cost}=90$).

The results obtained are presented in Figs 1and 2. Fig. 1 illustrates the structure of the diet for the situation when economics is preferred to the quality (Scenario II). Fig. 2 illustrates the level of ration costs dependent on the energy concentration of the diet. The range of the energy content of the ration was set between 12.3 and 13.7 MJ of metabolizable energy (ME).

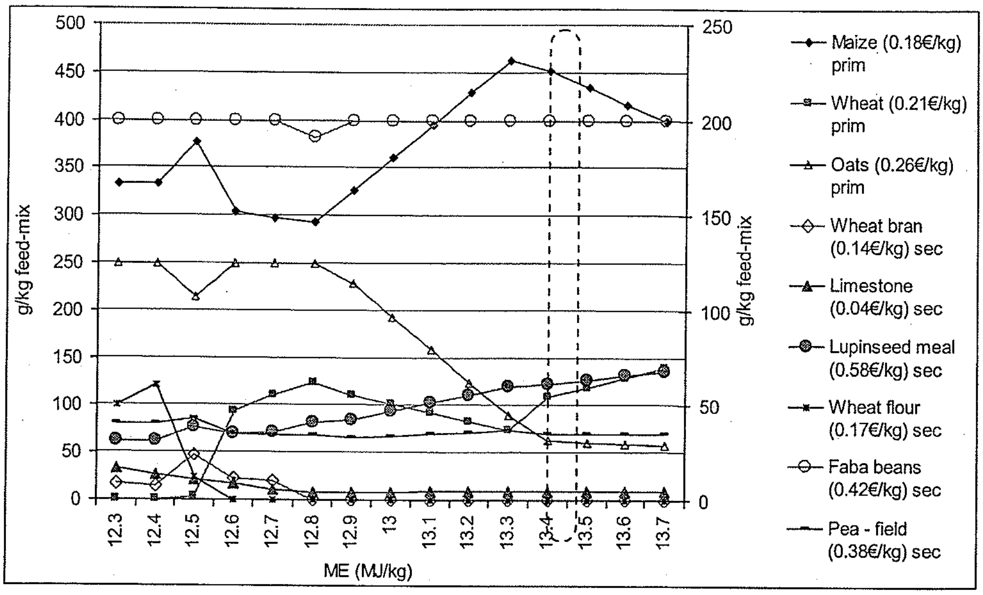

Fig. 1. Formulated feed-mix under scenario of high (W=90) ration cost importance (prim = primary axis; sec = secondary axis).

One of the factors that define how much a pig is going to eat is the energy content of the feed-mix. If the feed-mix is more concentrated, an animal is going to eat less, and vice versa (Blair, 2007). Fig. 1 presents formulated rations for the analysed fattening period. It is obvious that the energy content of the ration strongly influences selection of the feed. With increasing energy content, the quantity of maize increases and the quantity of oats decreases. From Fig. 1, it is apparent that in spite of expensive faba-beans, it enters into the solution, which is due to its favourable amino acids structure. The same holds for pea. Both are important substitutes for banned synthetic amino acid supplements.

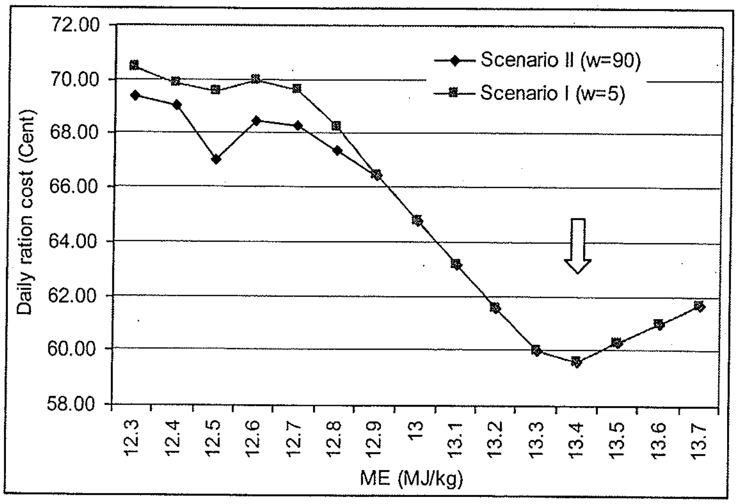

Fig. 2. Daily ration costs dependent on the feed-mix energy content.

The difference in daily ration costs between different energy concentrations is obvious. It ranges from 59.61 cents up to 70.43 / 69.42 cents per day per pig (scenario I/II). In any case, it should be an important issue to find the 'optimal' energy concentration of feed-mix in the daily management of organic pork production. In the Fig. 2 daily ration costs are presented for both scenarios. It is apparent that for analysed case importance of diet cost (Scenario II) has major influence only in the range of lower energy concentrations of feed-mixes (12.8 MJ kg^{-1} backwards), while from 12.9 MJ kg^{-1} onwards the trend of cost is the same. This is due to the fact that a feed-mix with lower energy content is harder to formulate especially more balanced one, which highly increases the costs. Consequently the minimal cost is achieved at relatively high energy concentration of feed-mix (Fig. 2), which is not usual in organic practise that is general less intensive. One could have legitimate scruples about the discrepancy between these results and practice, which is mainly due to poor quality of organically produced cereals in the sense of high nutritive value variability.

CONCLUSIONS

The results of this study show that the three phase optimization approach, supported by mathematical programming (LP and WGP with PF), can be efficiently applied to the diet formulation for organic pork production. The tool enables formulation of efficient diets, since it supports the farmer to find the optimal ration' energy content under various economic circumstances. With application of this tool problems like unbalanced protein composition, increased feed cost, increased burdening of the environment etc. might be mitigated. In this way the discrepancy between the aim of organic farming and practice could be reduced.

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Linear and weighted goal programming in livestock production: an example of organic pig farming

Jaka ŽGAJNAR[1] **and Stane KAVČIČ**[2]
[1]University of Ljubljana, Biotechnical Faculty, Department of Animal Science, Groblje 3, SI-1230 Domžale, Slovenia. e-mail: jaka.zgajnar@bfro.uni-lj.si
[2]The same address as [1] e-mail: stane.kavcic@bfro.uni-lj.si

The paper presents an optimization approach that merges linear programming and weighted goal programming. It is applied in a spreadsheet tool for organic pig ration formulation. The formulation process is based on a three-stage procedure: In the first step, common least-cost rations with different energy contents are formulated. In the second stage, a sub-model based on weighted goal programming supported by a system of penalty functions formulate nutritionally balanced and economically acceptable rations that also fulfil conditions demanded by organic farming. In the third phase, the ration formulation procedure stops when the most efficient ration is selected. The results obtained for a hypothetical farm confirmed the applicability of the implemented approach.

Keywords: linear programming, weighted goal programming, ration costs, organic farming, pork production

1. INTRODUCTION

Nowadays, livestock production demands precise management that leads to economically efficient and publicly acceptable production. This is possible through a very diverse range of measures. Due to the high share of ration cost within total production costs, ration formulation (optimization) is becoming a crucial task, especially in organic farming, which is globally characterized by higher production costs and affected by strict organic production policy constraints. However, pork production is also a livestock activity where unbalanced rations have significant negative impacts on the environment, especially if economics are taken as the most important criterion. Therefore, it is necessary to treat these kinds of problems as multiple criteria decision problems. Specifically, organic fattening that is confronted with the lack of availability of pure amino acids that results in a more unbalanced protein composition, increased feed cost, and, contrary to organic philosophy, an increased load of excessive nitrogen from manure on the environment [3]. In order to help breeders to deal with these challenges, numerous tools based on mathematical programming (MP) paradigms have been developed.

The first approach of this kind was conducted by [11], who applied the linear programming (LP) paradigm in order to formulate rations on a least-cost basis. This method was very popular in the past, especially after the rapid developments in personal computers. In the 1960s, it became a classical approach for the formulation of animal diets as well as feed mixes [2]. More recently, [5] stressed that the daily routine of ration formulation is one of the fields in which LP is most widely used.

Common to all LP problems is the concept of constraint optimization, which means that one tries to find the optimum of a single objective function. However, the exclusive reliance on just one objective (cost function) as the most important decision criteria is one of the reasons why the LP paradigm may be a deficient method in the process of ration formulation [8] and [9]. [7] stressed that, in practice, decision makers never formulate rations exclusively on the basis of a single objective, but rather on the basis of several different objectives, of which economic issues are only one of many concerns.

In common LP models for pig ration formulation, animal amino acid requirements are usually expressed in terms of minimal concentrations. Such models do not consider the total exceeded amount of protein or its quality, as long as the minimal amounts of essential amino acids are satisfied [1]. Furthermore, the same authors stressed that 'economically optimal' diets are often too rich in protein, which directly burdens the environment and does not improve animal growth. This problem could partly be solved by adding additional upper or lower constraints. However, this addition might rapidly lead into an over-constraint model that has no feasible solution. This problem is also related to the next LP drawback: the rigidity of constraints (right hand side (RHS)) [8]. This means that no constraint (e.g., the given nutrition requirements) violation is allowed at all. However, relatively small deviations in the RHS would not seriously affect animal welfare, but would result in a feasible solution [7].

Numerous methodological developments in the field of MP have eased these problems of the LP paradigm [4]. For instance, in the field of animal nutrition, [8] introduced goal programming (GP) and its improvement with a system of penalty function (PF), as well as multi-objective programming (MOP) as ways to incorporate more than one objective function. Similarly, [7] applied interactive methodologies where the optimal ration is achieved through 'computer dialog', and [5] addressed a multi-criteria fractional model.

The purpose of this paper is to present a spreadsheet tool for organic pig ration formulation, designed as a three-phase optimization approach that merges two normative MP techniques. The first part of the paper provides a brief overview of weighted goal programming (WGP) and the penalty function as the main method. This is followed by a short description of the optimization tool. Finally, the characteristics of the analysed case are presented, followed by the results and discussion.

2. MATERIALS AND METHODS

2.1. Weighted goal programming supported by a system of penalty functions

Based on the approaches reported in the literature and taking into account the primary aim of the tool presented in this paper, we decided to apply the WGP approach. In the context of ration formulation, the approach was introduced by [8].

WGP formulation is expressed as a mathematical model with a single objective (achievement) function (the weighted sum of the deviations variables). The optimal compromise solution is found through the philosophy of 'distance measure' that measures the discrepancy between the desired goal and the performance level of a goal. To consider all goals simultaneously, normalization techniques should be applied [10].

[8] introduced the PF paradigm into the WGP to keep deviations within desired limits and to distinguish between different levels of deviations. This system is coupled with the achievement function (WGP) through penalty coefficients and with additional constraints defining deviation intervals. Such an approach enables one to define allowable positive and negative deviation intervals separately for each goal. Depending on the goal's characteristics (nature and importance of 100% matching), these intervals might be different. Sensitivity is dependent on the number and size of defined intervals and the penalty scale utilized (s_i; for $i = 1$ to n).

2.2. Tool for three-phase ration formulation

The presented optimization tool for organic pig ration formulation was developed in Microsoft Excel as an add-in application. This tool is capable of formulating least-cost, nutritionally balanced and environmentally acceptable rations for 'organically' growing pigs in different production periods. In addition, it provides information about which feed mix provides the optimal energy content.

The tool is organized as a three-phase approach (Figure 1) that merges two sub-models based on MP techniques. The first sub-model is an example of a common least-cost ration formulation, based on the LP paradigm. The purpose of including this sub-model into the tool is to obtain an approximate estimate of expected ration cost. In this manner, the tool calculates the target economic goal, which is one of the goals in the second sub-model. Therefore, the first sub-model is, from the perspective of constraints, as simple as possible and is intended to exclusively measure the 'rough' cost estimation. Through cost function, it is linked to the second sub-model. The latter is based on WGP and is supported by a system of a six-sided PF. In this approach, the desired nutrition levels and ration costs are modelled as goals instead of constraints. Moreover, in the second sub-model, additional constraints are added that have an indirect influence on the environment. Consequentially, the model is much more complex and ultimately yields a better solution.

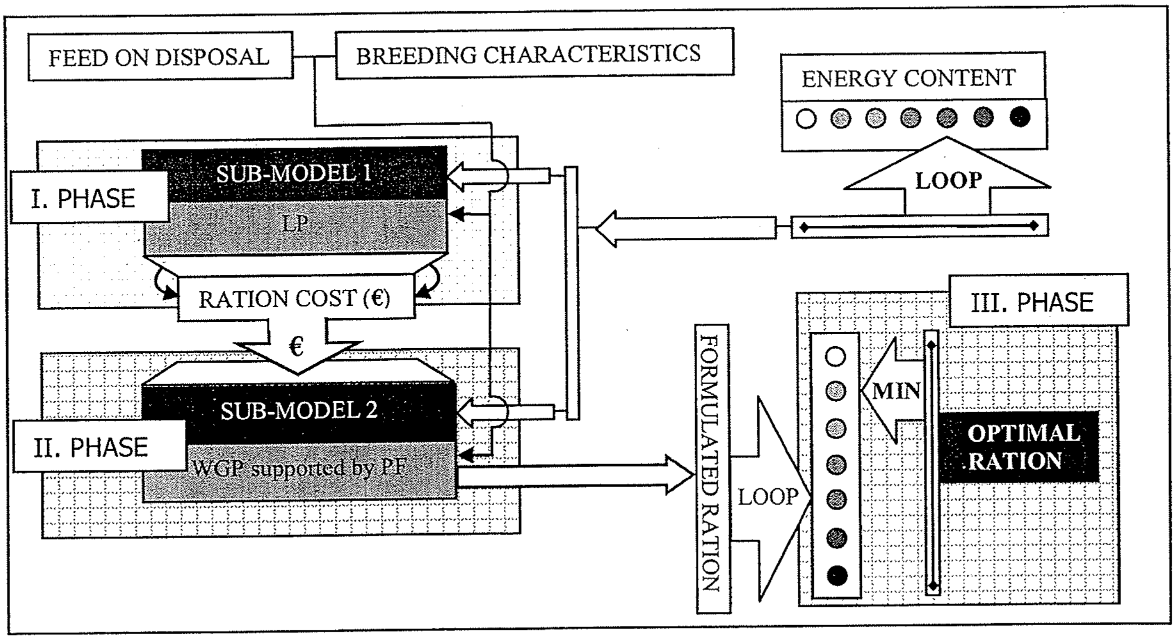

Figure 1: The scheme of the tool for three-phase organic pig ration formulation

Due to the importance of the feed mix's energy concentration and its influence on the ration structure and cost, the tool also includes a third phase (Figure 1). In this phase, a macro loop is added that runs the first and the second sub-models for n-times, and consequently it yields n–formulated rations. The number of iterations in the third phase depends on the starting/ending energy content of the feed mix and on the energy rise in each iteration step (e.g., 0.1 MJ/kg). From the n-obtained solutions, the tool selects the cheapest option and marks it as the 'optimal' feed mix structure for this given example.

2.3. Mathematical formulation of the first and the second sub-model

The first sub-model (LP) is formulated as shown in equation (1), equation (4a) and equation (7). It mostly relies on the economic (ration cost) function, C, and satisfies only the most important nutrition requirements coefficients, b_i, also known as RHS. In the first optimization phase, the desired element is the ration at the lowest possible cost (C).

$$\min C = \sum_{j=1}^{n} c_j * X_j \qquad \text{such that} \tag{1}$$

$$\min Z = s_1 \sum_{i=1}^{k} w_i \frac{d_{i1}^- + d_{i1}^+}{g_i} + s_2 \sum_{i=1}^{k} w_i \frac{d_{i2}^- + d_{i2}^+}{g_i} \qquad \text{such that} \tag{2}$$

$$\sum_{j=1}^{n} a_{ij} X_j + d_{i1}^- + d_{i2}^- - d_{i1}^+ - d_{i2}^+ = g_i \qquad \text{for all } i = 1 \text{ to r and } g_i \neq 0 \tag{3}$$

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \qquad \text{for all } i=1 \text{ to m} \tag{4a}$$

$$\sum_{j=1}^{n} \left(a_{ij} - (R^{\%}) a_{kj}\right) X_j \leq 0 \qquad \text{for all } i=1 \text{ to m} \quad \text{and } i \neq k \tag{4b}$$

$$d_{i1}^- \leq g_i - p_{i1}^{\min} g_i \qquad \text{for all } i=1 \text{ to r} \tag{5a}$$

$$d_{i1}^- + d_{i2}^- \leq g_i - p_{i2}^{\min} g_i \qquad \text{for all } i=1 \text{ to r} \tag{5b}$$

$$d_{i1}^+ \leq p_{i1}^{\max} g_i - g_i \qquad \text{for all } i=1 \text{ to r} \tag{6a}$$

$$d_{i1}^+ + d_{i2}^+ \leq p_{i2}^{\max} g_i - g_i \qquad \text{for all } i=1 \text{ to r} \tag{6b}$$

$$d_{i1}^+, d_{i1}^-, d_{i2}^+, d_{i2}^-, X_j \geq 0 \tag{7}$$

The second sub-model (WGP with PF) is formulated as shown in equation (2) to equation (7). The achievement function, Z, expressed in equation (2), is defined as the weighted sum of the undesired deviation variables (d_{i1}^+, d_{i1}^-, d_{i2}^+, d_{i2}^-) from the observed goals (g_i), multiplied by the belonging penalty coefficients (s_1 and s_2) that measure the slope of the penalty function. The obtained sum-product is the subject of the minimization in equation (2). The relative importance of each goal is represented by the weights (w_i) associated with the corresponding positive or negative deviations. Penalty intervals (p_{i1}^{min}, p_{i1}^{max}, p_{i2}^{min}, p_{i2}^{max}) are in place to prevent uncontrolled deviations (equation (5a) to equation (6b)) within each goal. Because of the normalization process, only goals that have non-zero target values (equation (3)) could be relaxed with positive and negative deviations. The obtained target value, C, in the first sub-model enters into the second sub-model (WGP with PF) through the 'cost goal' ($g_i = C$). This is also the only case where negative deviation is neither penalized nor restricted to intervals. All other constraints that have no defined target values or no priority attributes are considered in equation (4a). All upper bounds for ratios (R%) are transformed into linear equations with equation (4b), and the same holds for lower bounds, which should be multiplied by –1. The non-negativity condition for both models is considered in equation (7).

2.4. Analysed example

The tool has been applied for hypothetical organic pork production, with an average genotype for less intensive fattening. In this paper, we present only the fattening period between 50 kg and 100 kg with an average daily gain of 700 g. We considered that the tool should formulate the complete ration/feed mix in relation to the nutritional requirements. It is presumed that most of the fodder is produced at the farm under organic conditions and is evaluated with the full cost approach. The rest of the feed (less than 20%) that cannot be produced at the farm is accounted for at market price. However, no synthetic substances (e.g., amino acid supplements) could be added, since they are banned by law.

The nutritional requirements (metabolizable energy (35.2 MJ/day), crude protein (399 g/day), amino acids (Lys: 19.7 g/day; Met+Cys: 11.3 g/day; Thr: 13 g/day; Trp:

3.6 g/day) and minerals (Ca: 12.88 g/day; P: 11.59 g/day; $P_{available}$: 4.89 g/day; Na: 2.58 g/day)) are taken from [3]. In order to prevent an unrealistic solution with too much of one feed in the diet, we considered recommendations for maximal feed inclusion [3] and [6], namely, through additional upper-bound constraints (Table 1). In the process of ration formulation, the tool could choose between 12 different feeds (Table 1) that could be produced at the farm (except for dehydrated alfalfa, brewer's dried yeast and potato protein concentrate that could be purchased at market price), and four mineral components (limestone, salt, monocalcium phosphate and dicalcium phosphate) that could be purchased at market price.

Table 1: Prices and nutritive values of available feed and their suggested maximal share of the ration

Feed on disposal	Price* (cents/kg)	ME MJ/kg	DM g/kg	CP g/kg	Lys g/kg	Met+Cys g/kg	Thr g/kg	Trp g/kg	Max** %
Maize	18	14.1	880	85	2.5	3.5	3.0	0.8	0.6
Wheat	21	13.8	880	120	3.4	4.5	3.5	1.5	0.7
Barley	21	12.6	880	106	3.8	3.7	3.7	1.4	-
Oats	26	11.2	880	108	4.3	4.1	3.7	1.4	0.25
Wheat flour	17	12.5	880	167	7.3	5.6	6.5	2.0	0.15
Wheat bran	14	8.3	880	141	6.2	5.0	5.5	2.5	0.25
Alfalfa, dehydrated	33	6.1	910	180	8.7	4.5	7.8	2.9	-
Yeast, brewer's dried	71	13.2	900	452	32.1	11.7	21.8	5.1	0.05
Potato protein concentrate	132	15.7	930	780	56.9	20.1	45.3	10.6	0.15
Lupin seed meal	58	14.1	890	349	15.4	7.8	12.0	2.6	0.15
Faba beans	42	12.7	870	254	16.2	5.2	8.9	2.2	0.2
Pea-field	38	13.4	890	228	15.0	5.2	7.8	1.9	0.3

**Prices are estimated with model calculations—own source*

*** Suggested maximum inclusion of feedstuffs in pig diets*

The tool offers the option to switch between goals and constraints, depending on the needs and preferences of the decision maker. In the analysed case, we chose 10 goals (Table 2) that were to be met as accurately as possible.

Table 2: Importance of goals with corresponding penalty function intervals

Goal	Unit (day^{-1})	Weight (w_i)	Penalty function intervals p_{i1}^+ %	p_{i1}^- %	p_{i2}^+ %	p_{i2}^- %	Together p_i^+ %	p_i^- %
ME	MJ	75	1	0	2	0	3	0
CP	g	60	1	0	2	0	3	0
Lys	g	80	5	1	5	3	10	4
Met + Cys	g	60	5	1	5	3	10	4
Thr and Trp	g	60	5	1	10	3	15	4
$P_{available}$	g	40	3	1	5	3	8	4
Ca and Na	g	30	3	1	5	3	8	4
Cost	cent	90	10	∞	20	∞	30	∞

p_{i1}^+, p_{i1}^-, p_{i2}^+, p_{i2}^-: penalty intervals at the first and the second stage

The importance of each goal is defined by belonging weights (wi) ranging from zero to 100. Relatively high values are set for amino acids, since the reduction of an unbalanced protein fraction by increased protein quality (i.e., fulfilling the amino acid ratios in relation to the energy) reduces nitrogen excretion and pollution. For each goal, deviation intervals are defined separately (Table 2) and are measured in percentage deviation from the desired level. The cost goal is the only one that is not penalized for negative deviation; at the same time, the negative interval is unlimited.

3. RESULTS AND DISCUSSION

The main objective of the tool presented in this paper is to assist organic producers in formulating diets that are balanced and, at the same time, as cheap as possible. With a simple example, we present how the tool could be applied and the possible benefits of the utilized methods. We have presumed that the decision maker prepares a feed mix for growing pigs. For organic producers, this task is subject to numerous limitations and very complex constraints.

The range of the ration's energy content was set between 12.3 MJ and 13.7 MJ of metabolizable energy (ME) per kilogram of feed. The changing compositions of formulated rations are presented in Figure 1. In the second part of this paper, we compared ration cost obtained by the presented tool and a common least-cost approach.

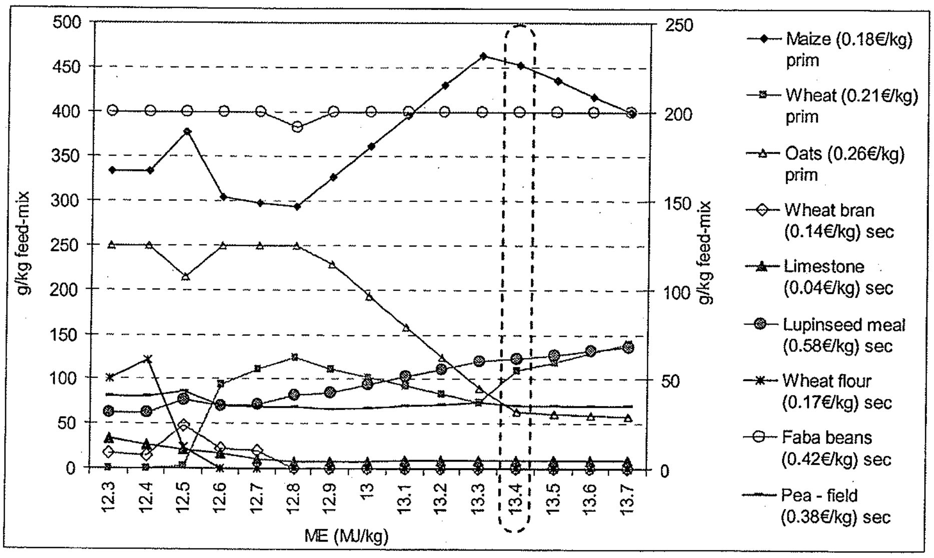

Figure 1: Formulated feed mix for organic pork production (prim = primary axis; sec = secondary axis)

One of the factors that define how much a pig is going to eat is the energy content of the feed mix. If the feed mix has a higher energy concentration, an animal will eat less, and vice versa [3]. Figure 1 presents formulated rations for the analysed fattening period. It is obvious that the energy content of the ration strongly influences the selection of the feed. With increasing energy content, the quantity of maize increases and the quantity of oats decreases. From Figure 1, it is apparent that, in spite of their high cost, faba beans enter into the solution due to their favourable amino acids structure. The same holds for peas; both are important substitutes for banned synthetic amino acid supplements.

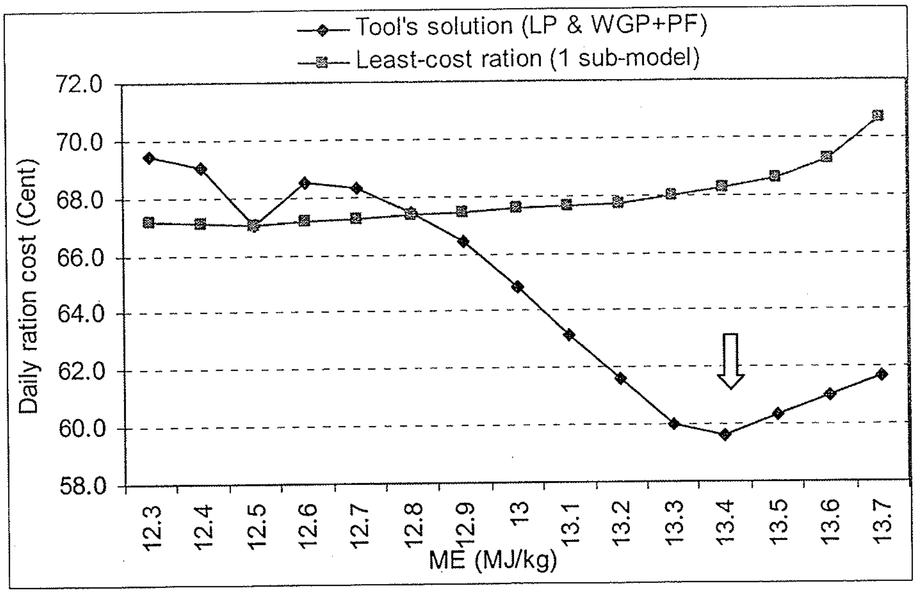

Figure 2: Daily ration costs dependent on the feed mix energy content; cost comparison of the least-cost ration and the tool solution

The difference in daily ration costs for different energy concentrations is obvious. The cost ranges from 59.61 cents up to 69.42 cents per day per pig. In any case, finding the 'optimal' energy concentration of feed mix in the daily management of organic pork production should be considered important because a feed mix with a lower energy content is harder to formulate, especially a more balanced one, which highly increases costs. Consequently, the minimal cost is achieved at a relatively high energy concentration (13.4 MJ/kg) of feed mix (Figure 2), which is unusual in organic practises that are generally less intensive. One could have legitimate doubts about the discrepancy between these results and actual practice, mainly because of the poor quality of organically produced cereals, in the sense of high nutritive value variability. However, the obtained results (Figure 2) confirm the benefits of the applied approach. Specifically, the significant discrepancy between the ration cost of the least-cost ration and the one obtained with the multiple criteria decision paradigm applied in the presented tool shows it is possible to achieve a more balanced ration (in the sense of total deviation from the target value) with a simultaneous reduction in daily ration cost of almost 13 %. One would expect the opposite situation that a more balanced ration results in increased costs. In the analysed example, cost reduction mainly occurs due to allowed negative deviations and controlled [constrained] positive deviations as result of weights and intervals of penalty functions.

4. Conclusions

The results of this study show that the three-phase optimization approach supported by mathematical programming (LP and WGP with PF) can be efficiently applied to diet formulation for organic pork production. The utilization of a multiple criteria optimization paradigm improves the quality of the obtained solution. The tool enables the formulation of efficient diets, since it supports the farmer in finding the optimal ration under various economic circumstances. With the application of this tool, problems such as unbalanced protein composition, increased feed cost, increased burdening of the environment and so forth might be mitigated. In this way, the discrepancy between the aims of organic farming and its practice may be reduced.

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EKONOMSKO OPTIMIRANJE DNEVNIH OBROKOV ZA KRAVE MOLZNICE

Jaka ŽGAJNAR[1], Stane KAVČIČ[2]

IZVLEČEK

V prispevku je predstavljeno orodje za izračun dnevnih obrokov krav molznic, zasnovano kot elektronska preglednica. Orodje sestoji iz dveh pod-modelov. Prvi je klasični linearni program, drugi pa aplicira tehniko tehtanega ciljnega programiranja z vgrajeno kazensko funkcijo. S kombinacijo obeh pristopov iščemo najcenejši dnevni obrok, ki upošteva sodobne zahteve v prehrani visoko-proizvodnih krav. Uporabnost pristopa ponazarjamo s primeri obrokov pri dnevni mlečnosti 25 kg mleka in na njih prikazujemo, da je z razvitim orodjem mogoče sočasno zasledovati ekonomske (učinkovitost) in prehranske (prilagodljivost na razpoložljivo krmo in prehranske zahteve živali) vidike v praktični prireji mleka.

ECONOMIC OPTIMISATION OF DAILY RATIONS FOR DAIRY COWS

ABSTRACT

The paper presents spreadsheet tool for the formulation of a daily dairy cow ration. It is constructed on the basis of two linked sub-models merging the common linear programming model and the weighted-goal programming model with a penalty function. With combination of both approaches it is intended to find least cost daily ration, considering up-to-date requirements of high yielding dairy cows. Applicability of the tool is illustrated with rations for 25 kg daily milk yield. The results obtained confirm the benefits of the applied approach. The tool provides efficient rations in both economic and nutritive terms, allowing for adjustment to feed available and nutrition requirements of the animals. In this way it can support daily management on dairy farms.

1. UVOD IN PREGLED LITERATURE

Kot v vsaki ekonomski dejavnosti tudi v prireji mleka rejci skušajo proizvajati na ekonomsko učinkovit način. Stroške in prihodke v prireji mleka določajo številni zunanji dejavniki, povezani s tržnimi (kot npr. dvig stroškov krme ali gnojil) in naravnimi pogoji (nizki pridelki pri pridelavi krme zaradi vremenskih neprilik) ter političnimi odločitvami (npr. postopen dvig kvot in njihova odprava čez nekaj let). Ker na številnih kmetijah stroški krme dosegajo med 50 in 60 % vseh spremenljivih stroškov prireje mleka, je sestavljanje dnevnih obrokov krav pomemben vzvod za zniževanje stroškov prireje. Z naraščajočo nestabilnostjo cen krme postaja pogosto prilagajanje aktualnim tržnim razmeram toliko pomembnejše.

Sestavljanje učinkovitih krmnih obrokov je kompleksna in časovno zahtevna naloga, saj naj bi pri njem upoštevali prehranske, ekonomske in okoljske zahteve. V praksi vseeno

[1] Asistent, univ. dipl. ing. zoot., Biotehniška fakulteta, Oddelek za zootehniko, Groblje 3, SI-1230 Domžale jaka.zgajnar@bfro.uni-lj.si

[2] Izr. prof., dr., mag., univ. dipl. ing. kmet., isti naslov

največkrat obroke sestavljamo izkustveno ali na podlagi pridobljenega teoretičnega znanja, včasih tudi po metodi učenja na podlagi lastnih napak, praviloma 'ročno'. V vseh teh primerih so neprehranski vidiki (ekonomski in okoljski) pogosto spregledani, kar praviloma zmanjša učinkovitost same reje.
Pregled literature nam nudi številne primere uporabe tehnik operacijskih raziskav za reševanje prehranskih problemov. Najpogosteje se za iskanje najcenejših obrokov uporablja normativna optimizacija (linearno programiranje), ki jo je prvi uporabil Waugh (1951). Kot ugotavlja Castrodeza s sod. (2005), je linearno programiranje (LP) vse do danes najpogosteje uporabljena tehnika pri sestavljanju obrokov za živali, kar še posebno velja za industrijo močne krme.
Čeprav je LP primerna metoda za reševanje prehranskih problemov, pa Rehman in Romero (1984; 1987) opozarjata na nekatere pomanjkljivosti, ki se izkažejo za kočljive zlasti v primeru sestavljanja obrokov, ki naj bodo učinkoviti tako v prehranskem kot ekonomskem smislu. Zanje so osnovne predpostavke LP preveč toge (zlasti ena ciljna funkcija in fiksnost omejitev), saj dopuščajo optimizacijo zgolj enega cilja naenkrat (npr. minimizacija stroškov). Nedvomno je sestavljanje obrokov bistveno bolj kompleksno. Poenostavitve, kot so upoštevanje zgolj enega cilja, lahko pripeljejo do neuporabne rešitve oziroma do primera da ta ne obstoji (problem togosti postavljenih omejitev). Zato so za oblikovanje obrokov primernejše tehnike večkriterijskega programiranja (Lara in Romero, 1994), v katere lahko vključimo večje število dejavnikov, kot so denimo učinki na okolje in dobrobit živali.
Druga deloma že izpostavljena pomanjkljivost povezana z LP se nanaša na t.i. 'togost' omejitev. V praksi nas to pogosto pripelje do dveh ključnih problemov. Prvi je da sistem enačb nima rešitve, lahko pa se zgodi tudi da rešitev obstoji, je pa zaradi prevelikih prekoračitev postavljenih zahtev le-ta neuporabna. Resnici na ljubo manjše odstopanje od posamezne omejitve v praksi ne bi imelo večjega vpliva npr. na dobrobit živali (Lara in Romero, 1994). Če se vrnemo k prehranskim problemom, se moramo zavedati, da so tudi prehranske potrebe živali in hranilne snovi razpoložljive krme podvržene določenim odstopanjem - 'napakam' - in je torej nesmiselno zahtevati, da v dnevnem obroku za vsako ceno pokrijemo prav vse zahteve, pri tem pa zanemarimo prekoračitve, ki so prav tako drage in zaradi neravnovesja izračunanega obroka ne zagotavljajo teoretične (izračunane) prireje.
Možen pristop za odpravo t.i. 'togosti' je arbitrarna pretvorba nasprotujočih si omejitev, vendar le-ta lahko vodi v odprt sistem enačb, kateri pa navadno nima smiselne rešitve (Ferguson s sod., 2006). Poleg tega je potrebno tudi precej specifičnega ekspertnega znanja, kar bistveno poslabša uporabnost takšnega orodja za potencialnega končnega uporabnika. Naslednji problem povezan z omejitvami pri klasičnem LP so tiste omejitve, ki so definirane zgolj enostransko (najmanj/največ). Slednje lahko zaradi neizravnanosti obroka vodijo v njegovo podražitev ali kar postaja v sedanjem času še pomembnejše, lahko povečajo onesnaženje s presežnimi elementi ali izpusti toplogrednih plinov (Brink s sod., 2001) Deloma je problem rešljiv s postavitvijo dodatnih omejitev, a le do določene mere saj lahko hitro pripelje do zelo kompleksnega modela, ki nima rešitve (Lara, 1993). Poleg tega omenjeni pristop ni najboljši če naj bi bilo orodje za sestavljanj krmnih obrokov namenjeno širšemu krogu uporabnikov.
Vse izpostavljene pomanjkljivosti LP lahko deloma zaobidemo s večkriterijskimi pristopi odločanja (Rehman in Romero, 1984). Najbolj pogosto uporabljena tehnika je ciljno programiranje in sicer tehtano ciljno programiranje (angl. weighted goal programming - WGP; Tamiz in sod., 1998).

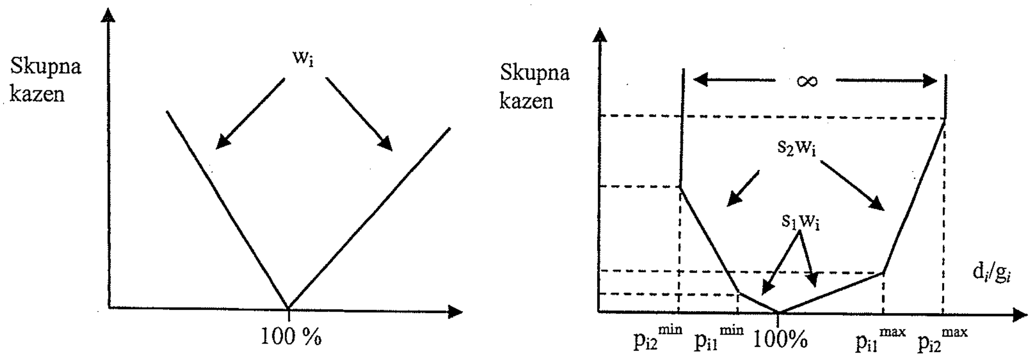
Ciljno programiranje (GP) je bilo razvito z namenom zaobiti pomanjkljivosti klasičnega LP. V letu 1955 sta ga razvila Charnes in Cooper in ga sprva poimenovala omejena regresija in šele šest let pozneje kot ciljni program (Ignizio in Romero, 2003). Gre za posebno kompromisno metodo reševanja večkriterijskih problemov, ki predpostavlja, da odločevalec pozna ciljne vrednosti in lahko določi njihov relativen pomen (Liu, 2008). Pri reševanju realnih problemov so namreč kontradiktorni cilji dosegljivi le na račun 'žrtvovanja' drugih ciljev – s tem pa je izpolnjen pogoj za dosego Paretovega optimuma (Liu,. 2008).
Tamiz in sod. (1998) ugotavljajo, da je metoda svoj razmah doživela šele v sredini sedemdesetih let prejšnjega stoletja. V literaturi se pojavljajo številne različice, med katerimi so najpogostejše tehtano ciljno programiranje (WGP), t.i. prioritetno ciljno programiranje (LGP) in t.i. ciljno programiranje MINMAX (MGP) poznano tudi kot »fuzzy« programiranje (Romero, 2004). Bistvena razlika med njimi je v obliki namenske funkcije, s tem pa v predpostavljeni filozofiji upravljalca – kmetijskega gospodarja.
Dejansko gre za posebno obliko LP kar z drugimi besedami pomeni da je problem rešljiv s simplex algoritmom (Rehman in Romero, 1993). To dejstvo je pomembno zlasti v primeru ko razvijamo orodje namenjeno širši uporabi, saj ga lahko razvijemo in rešimo s pomočjo najbolj razširjenih elektronskih preglednic (npr. MS Excel).
Namen prispevka je prikazati, kako lahko tehnike matematičnega programiranja uporabimo pri uporabniško 'prijaznem' orodju za podporo pri operativnem dnevnem odločanju v prireji mleka. Prav s tem namenom je orodje razvito v MS Excelu, saj je ta programska oprema danes razširjena na večini osebnih računalnikov, s tema pa dostopna potencialnim uporabnikom. Kratki razlagi uporabljenih optimizacijskih tehnik ter kazenske funkcije sledi opis uporabljenega pristopa. Po opisu značilnosti analiziranega primera so prikazani dobljeni rezultati skupaj z razpravo. Prispevek zaokrožamo z nekaj zaključki, ki nas silijo v nadaljnje delo na tem področju.

2. MATERIAL IN METODE DELA

2.1 Tehtano ciljno programiranje in kazenska funkcija

Tehtano ciljno programiranje nam omogoča sočasno optimiranje večjega števila ciljev. Slednje dobimo tako, da želene omejitve pretvorimo v cilje. Pri izbiri ključnih omejitev, ki jih bomo uporabili kot cilje, si lahko pomagamo z analizo občutljivosti. To velja zlasti kadar nismo povsem prepričani, katere omejitve izbrati. Postavljenim ciljem lahko teoretično popolnoma zadostimo, včasih le deloma, v ekstremnih primerih pa srečamo tudi take, ki se jim ne moremo približati. Odstopanje od ciljev omogočimo s spremenljivkami, ki jih opredelimo za vsak cilj posebej bodisi v pozitivno oziroma negativno smer in torej pomenijo pozitivno ali negativno odstopanje od zastavljenega cilja. Tako zapisan matematičen model ima eno samo namensko funkcijo, ki išče najmanjšo vsoto odstopanj od zastavljenih ciljev. Dobljen rezultat predstavlja kompromisno rešitev med navadno nasprotujočimi si cilji. V tem je tudi največja razlika med LP in WGP - namenska funkcija pri slednjem minimira nezaželena odstopanja od zastavljenih ciljev in ne minimira ali maksimira ciljev samih, tako kot pri LP (Ferguson s sod., 2006).
Kakovost dobljenega rezultata je odvisna od izbire t.i. 'prednostnih uteži'. S slednjimi na nek način 'kaznujemo' neželeno odstopanje od ciljnih vrednosti, s tem pa postavimo tudi prioritetno lestvico ciljev. Vrednosti uteži lahko definiramo na osnovi ekspertne ocene oziroma s pomočjo analize senčnih cen. Da bi zmanjšali pristranskost dobljenih rezultatov, pa Gass (1987) predlaga uporabo zahtevnejših matematičnih tehnik.
Narava ciljev je navadno zelo različna, zlasti če gre za multidisciplinaren pristop, kar z drugimi besedami pomeni, da so cilji izraženi v različnih enotah. Posledično odstopanj ne

moremo enostavno seštevati. Da bi se temu problemu izognili, odstopanja 'normaliziramo' (Tamiz in sod., 1998) ((zaželena - dejanska)/zaželena vrednost) in jih na ta način pretvorimo v primerljive.
Pri tehtanem ciljnem programiranju je vsako mejno odstopanje pri posamičnem cilju enako ovrednoteno (konstantna kazen) neodvisno od tega, kako močno je odstopanje od ciljne vrednosti. Z vidika rešitve to seveda predstavlja pomanjkljivost. Za praktično sestavljanje obrokov je namreč močno odstopanje od zastavljenih ciljev (normativov) običajno bistveno manj zaželeno kot če je to odstopanje zelo majhno. Da bi odstopanja ohranili znotraj določenih tolerančnih meja in da bi lahko razlikovali v ovrednotenju različno intenzivnih odstopanj, lahko WGP nadgradimo s kazenskimi funkcijami (angl. Penalty function PF) (slika 1). Slednje nam omogočajo natančno nastavitev pozitivnih in negativnih intervalov odstopanj za vsak cilj posebej. Odvisno od značilnosti posameznega cilja (njegove narave in pomembnosti, da ga 100 % dosežemo), so ti intervali lahko tudi različni. Občutljivost kazenske funkcije je odvisna od števila in velikosti definiranih intervalov in od uporabljenih uteži znotraj posameznega intervala. Vsako odstopanje namreč obravnavamo na podlagi predhodno določene večstranske kazenske funkcije in v nobenem primeru ne sme preseči zunanjih meja postavljenih intervalov. Ker je kazenska funkcija povezana s tehtanim ciljnim programom preko namenske funkcije, predstavlja pomemben dejavnik pri minimiranju vsote vseh odstopanj.

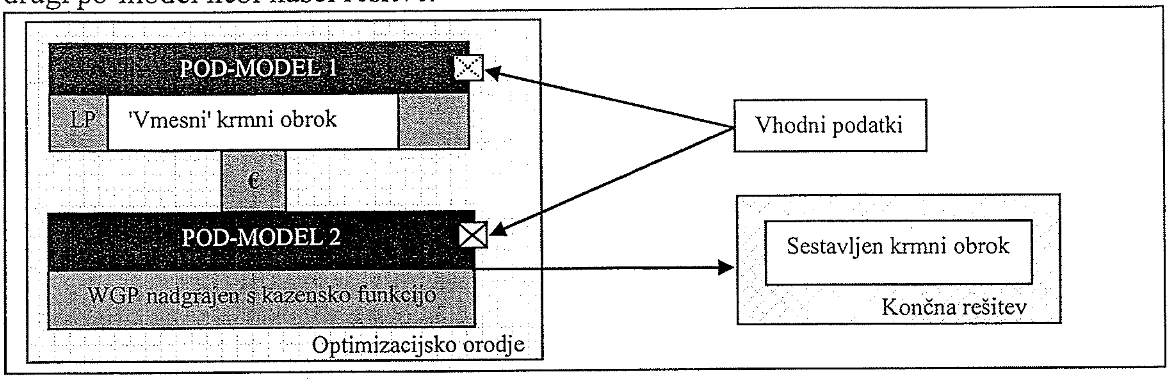


Slika 1: Shematičen prikaz konstantne in več-stopenjske kazenske funkcije (prilagojeno po Romero in Rehman, 2003)

Figure 1: Scheme of constant penalty and scheme of multi-sided penalty function (adapted from Romero and Rehman, 2003)

2.2 Opis razvitega orodja

Orodje za sestavljanje obrokov za krave je bilo razvito v MS Excelu. Zasnovano je kot dvofazni model (vsebuje dva pod-modela), ki temelji na tehnikah matematičnega programiranja (LP in WGP z vgrajenimi kazenskimi funkcijami). Prvi pod-model je klasičen primer iskanja najcenejšega obroka (temelji na LP). V našem primeru služi kot orodje za izračun približne ocene skupnih stroškov obroka. Ta podatek namreč potrebujemo v drugem pod-modelu, saj je 'dopusten' strošek krmnega obroka eden izmed ciljev (slika 2). Prednost uporabljenega pristopa je predvsem v tem, da lahko model sam oceni skupni strošek obroka, ki se seveda pri spremembah cen krme zelo hitro spreminja. Ker so si prehranske potrebe lahko v nasprotju, zlasti pri visoko proizvodnih kravah, je prvi pod-model poenostavljen in upošteva le najpomembnejše omejitve, kar se navadno odrazi v nekoliko nižji 'oceni' stroškov. Bistveno je namreč da v tej pri fazi model najde rešitev, kajti v nasprotnem primeru bi bila ciljna vrednost enaka nič in posledično tudi drugi po-model nebi našel rešitve.



Slika 2: Shematičen prikaz razvitega optimizacijskega orodja

Figure 2: Scheme of optimization tool

Orodje je razvito kot odprt sistem, kar pomeni, da se vsi vhodni podatki preračunajo za analiziran primer. To dosežemo s predhodno razvitim modelom (Žgajnar s sod., 2007), ki izračuna dnevne potrebe živali in je povezan z orodjem, ki je predmet tega prispevka.

2.3 Opis analiziranega primera

Orodje smo testirali na primeru sestavljanja dnevnega obroka za kravo molznico s telesno maso 650 kg na 150. dan laktacije. Predpostavili smo laktacijsko mlečnost 7.000 kg, na analizirani dan pa naj bi dala 25 kg mleka in bila v 90. dnevu brejosti. Najpomembnejše omejitve in cilje za analizirani primer prikazujemo v preglednici 1.

Pregl. 1: Dnevne potrebe krav molznic s 25 kg mleka in 90 dnevi brejosti, prikazane kot omejitve (LP) ali postavljeni cilji (WGP), ter uporabljeni parametri kazenske funkcije

Table 1: Daily requirements for dairy cow with 25 kg milk yield assuming 90 days of pregnancy, presented as constraints (LP) and set of goals (WGP), including applied penalty functions' parameters

		Dnevne potrebe Daily requirements Poletne/zimske Summer/winter		Kazenska funkcija / Penalty function				
				Interval 1		Interval 2		
		LP	WGP I / II	S1-	s1+	s2-	s2+	w
NEL	(MJ)	>122,4	122,4	0,5%	0,5%	5%	5%	100
ME / MP	(g)	>1.471,3	1.471,3	0,5%	0,5%	5%	5%	100
SS / DM	(kg)	<18,5	18,5	5%	0%	10%	0%	33
SV / CF min	(kg)	>3,3						
SV / CF max	(kg)	<4,8						
Ca	(g)	>104,1	104,1	2%	5%	20%	20%	5
P	(g)	>67,7	67,7	2%	5%	20%	20%	5
Ca:P	(%)	(1,5-2):1						
K:Na	(%)	(5,5-10):1						
Strošek /Cost	(cent)		*C1*	∞	10%	∞	20%	5/95
Min Seno/hay	(kg/day)	3						
Max Seno/hay	(kg/day)	5						
Max Travna silaža/ Grass silage	(kg/day)	30						
Max Koruzna silaža/ Maize silage	(kg/day)	30						
Max Sol/ Salt	(g/day)	30						
Max Bovisal zimski/ winter	(g/day)	240						
Max Bovisal letni/ summer	(g/day)	200						

Osnovni nabor omejitev je podoben pri obeh pod-modelih. Prehranske omejitve se razlikujejo le v matematičnem 'predznaku' (<, >, =) saj so pri tehtanem ciljnem programu zahteve po hranilnih snoveh transformirane v cilje (=). V primeru LP modela so upoštevane le najpomembnejše omejitve tipa maksimum (<) ali minimum (>), ki si niso nasprotujoče. To se seveda odrazi tudi v izračunanem obroku, ki ni vedno primeren za prakso. Vseeno pa smo v orodje vgradili to poenostavitev, saj LP model služi le grobi oceni najnižjih možnih stroškov dnevnega obroka. Nesporno je dobljen neizravnan obrok cenejši, takšna poenostavitev pa po eni strani omogoča potrebno rešitev in po drugi strani 'spodbuja' tehtani ciljni program z vgrajeno kazensko funkcijo k iskanju rešitve, ki po ceni čim manj odstopa od dosegljive v praksi.

Pri vsakodnevnem sestavljanju obrokov za živali moramo upoštevati tudi razpoložljive količine krme, ki jih lahko vključimo v dnevni obrok. V analiziranem primeru smo predvideli, da naj obrok vsebuje najmanj 3 kg mrve, ne sme pa preseči 5 kg le-te. Oba pod-modela tudi ne smeta preseči maksimalne količine koruzne in travne silaže, v analizi postavljene na 30 kg. Ker z orodjem lahko sestavljamo tako poletne kot zimske obroke, so predvidene različne količine rudninsko-vitaminskih mešanic (skladno z navodili proizvajalca).

Prvotna verzija WGP vsebuje šest ciljev, podprtih s kazenskimi funkcijami (pregl. 1). Relativen pomen posameznega cilja je določen z utežjo (w), katere vrednost se lahko giba med 0 in 100. Kot najpomembnejša cilja smo v našem primeru predvideli zadostitev potreb po energiji (NEL) in beljakovinah (presnovljive beljakovine), obema smo pripisali utež 100 in določili zelo interval odstopanja (0,5 % v prvi in 5 % v drugi stopnji). Veliko nižjo težo smo pripisali zauživanju suhe snovi, s katero ocenjujemo konzumacijsko sposobnost živali. Pri njem smo interval odstopanja določili le za negativno odstopanje od cilja, medtem ko zaradi praktičnih razlogov (konzumacijske sposobnosti) presežkov nismo dovolili. Poleg omenjenih smo uvedli dodatno omejitev, ki postavlja zgornjo mejo zauživanja suhe snovi iz voluminozne krme na 14 kg. Ker je s prehranskega vidika pomembneje zagotoviti ustrezno razmerje med Ca in P ter med K in Na kot doseči določene količine posameznih med njimi, smo za rudnine (Ca in P) predpostavili razmeroma nizke teže. Ostale rudnine so v izračun vključene preko več varnostnih zank, ki preprečujejo pomanjkanje ali pa njihove toksične koncentracije.

Z razvitim orodjem smo testirali, kako se spremeni 'optimalen' dnevni obrok, če cilju za minimiranje stroškov damo različen pomen (pripišemo različno težo). Analizo prikazujeta dva scenarija. Pri prvem (WGP I) je strošek obroka manj pomemben (relativna teža je samo 5), medtem ko je pri drugem (WGP II) njegov pomen povečan (w=95). V obeh scenarijih ostajajo intervali odstopanja enaki (+10 in + 20 %).

Razpoložljive sestavine obroka in njihove hranilne vrednosti so prikazane v pregl. 2. Seveda lahko v praksi hranilne vrednosti močno odstopajo od predpostavljenih, kar je predvsem pri voluminozni krmi odvisno zlasti od tehnologije, intenzivnosti pridelave kot tudi od drugi zunanjih dejavnikov (npr. količina padavin). Zato je pred sestavljanjem obrokov seveda vedno smiselno upoštevati hranilno vrednost dejansko razpoložljive krme, bodisi na podlagi kemijske analize ali vsaj organoleptične ocene.

Pregl. 2: Hranilna vrednost razpoložljive (predpostavljene) krme

Table 2: Nutritive value of feed on disposal

	SS/ DM (g/kg)	NEL (MJ/kg SS)/ (MJ/kg DM)	PB/ MP**	SV/ CF	Ca	P (g/kg SS)/ (g/kg DM)	Mg	Na	K	Cena ali LC/ Price or TC* (cent/kg)
Razpoložljiva krma Feed on disposal										
Seno/Hay	860	5,90	85,00	270	5,70	3,50	2,00	0,35	18,25	15,30
Koruzna silaža/ Maize silage	320	6,50	45,00	200	7,06	6,00	1,91	0,12	10,76	3,70
Travna silaža/ Grass silage	350	5,60	62,00	260	6,00	3,51	2,20	0,35	21,30	6,14
Trava - paša/ Grass - pasture	160	7,10	121,00	205	6,00	2,60	2,00	0,10	10,50	1,50
Koruza/ Maize	880	8,50	83,00		0,23	4,09	1,25	0,23	3,75	30,00
Pšenica/ Wheat	880	8,60	88,00		0,57	3,86	1,59	0,45	5,00	32,00
Repičine pogače/ Rapeseed cake	900	7,50	125,00		2,89	7,00	2,78	2,22	10,00	37,00
Sojine tropine/ Soya meal	880	8,20	215,00		3,41	7,84	2,61	1,14	20,00	46,00
K-18***	880	7,61	136,74		10,23	5,68	2,84	3,98	10,23	27,67
K-19***	880	7,61	146,51		10,23	5,68	2,84	5,11	10,23	30,00
Mineralne in vitaminske komponente Mineral and vitamin components										
Apnenec/ Limestone	950				400,00					16,40
MVM1****	930				160,00	100,00	36,00	120,00		67,56
MVM2****	930				210,00	70,00		135,00		58,08
Sol/Salt	950							400,00		50,00

* Izračun na podlagi lastne cene / Total cost approach

** Upoštevana je najnižja vrednost presnovljivih beljakovin / The lowest value of metabolisable protein is considered

*** Komercialna imena krme za krave molznice z različnimi vsebnostmi (%) presnovljivih beljakovin / Commercial names of dairy cows' feed containing different % of metabolisable proteins

**** Komercialni imeni za mineralno-vitaminske mešanice so 'Bovisal letni' in 'Bovisal zimski' /Commercial name of mineral-vitamin mixtures are Bovisal summer and Bovisal winter

V simulaciji smo predvideli, da vso voluminozno krmo (mrvo, koruzno in travno silažo, pašo) pridelamo na kmetiji. Ker ta krma praviloma ni predmet trgovanja, smo stroške njihove pridelave povzeli po modelnih kalkulacijah Kmetijskega inštituta Slovenije (KIS, 2009). Vso ostalo krmo in rudninsko-vitaminske mešanice smo obračunali po tržnih cenah (pregl. 2). Logično vprašanje, ki se poraja, je, kaj naj pridelujemo sami in kaj naj kupimo, da bi izboljšali ekonomski rezultat kmetovanja, vendar pa ta vidik ni predmet obravnave v tem prispevku.

3. REZULTATI IN RAZPRAVA

Orodje smo testirali na primeru, ki ga v vsakodnevni praksi pogosto srečamo (telesna masa krav 650 kg, dnevna mlečnost 25 kg, 90. dan brejosti). Opravili smo 4 simulacije, dve za zimsko in dve za poletno obdobje - pri slednjem smo v nabor razpoložljive krme vključili tudi pašo. Sestava dnevnih obrokov je prikazana v pregl. 3, vključno z rezultati

LP modela. Ti služijo le za oceno najnižjih možnih stroškov, zaradi že opisanih poenostavitev pa sestave teh obrokov niso vedno primerne za prakso.

Pregl. 3: Izračunani dnevni obroki s pomočjo LP (prvi pod-model) in WGP (drugi pod-model) (pri slednjem za dve različici pomena stroškov - scenarija)

Table 3: Obtained daily rations formulated with LP (first sub-model) and WGP (second sub-model) (for the last one with two different cost importance - scenarios)

	Dnevni obrok / Daily ration					
	Zimski / Winter			Poletni / Summer		
	LP	WGP I	WGP II	LP	WGP I	WGP II
Krma vključena v obrok (kg/dan) Feed used (kg/day)						
Seno / Hay	5,00	5,00	5,00	4,56	3,00	5,00
Koruzna silaža / Maize silage	25,16		10,33		15,18	17,22
Travna silaža / Grass silage	6,14	23,84	16,57		5,80	0,16
Paša / Pasture				69,23	34,58	32,08
Pšenica / Wheat	1,98	5,00	2,19			
Koruza / Maize	1,18	1,50	1,50	1,95	1,50	1,50
Sojine tropine / Soya meal	2,30					
K-18			3,56	3,08		
K-19	0,17	1,56				
Uporabljeni mineralni dodatki (g/dan) Mineral components used (g/day)						
Apnenec / Limestone		24,2	13,0		30,4	37,0
Bovisal Letni / Summer				104,6	56,8	50,2
Bovisal Zimski / Winter	61,1	34,8				
Sol / Salt	30,0	30,0	28,1		30,0	30,0
Strošek (€/dan) / Cost (€/day)	3,87	4,34	3,87	2,66	2,93	2,91
Stroškovno odstopanje/ Cost deviation (%)	0,0	12,2	0,0	0,0	10,2	9,3
Odstopanje od normativov/ Requirements deviations (%)						
NEL	0,0	-1,7	-2,2	0,0	-0,5	-0,5
PB / MP	0,0	0,0	0,0	39,0	0,0	0,0
Skupno odstopanje/ Total deviation*	56,3	10,1	37,0	69,6	27,2	30,7
Fizikalne značilnosti obroka/ Physical ration attribute						
SV / CF (%)	18	18	18	19	19	19
SS (kg/dan) / DM (kg/day)	18,5	18,5	18,5	17,8	18,0	17,9

*Skupna vsota odstopanj (vključno z odstopanji od normativov za minerale, ki niso predstavljeni v preglednici) / Total sum of deviations (including mineral deviations not presented in the table)

Med sestavo krmnih obrokov v poletnem in zimskem obdobju je po pričakovanju velika razlika, se pa ta pojavi tudi znotraj posameznega obdobja med obema scenarijema (pregl. 3). Prva je predvsem posledica razpoložljive paše v poletnem obdobju, ki je z vidika zagotavljanja hranilnih snovi najcenejša krma, druga bistvena razlika pa nastopi predvsem zaradi različne ekonomske teže (stroški obroka) vgrajene kazenske funkcije.
Pri zimskih obrokih (WGP I in WGP II) so potrebe po beljakovinah pokrite predvsem s travno silažo in kupljeno krmno mešanico K-19 (WGP I) oziroma K-18 (WGP II). Očitno je, da cene krme igrajo odločilno vlogo pri sestavi obroka, saj večji poudarek na

stroškovni strani prehrane (WGP II) pomembno zniža količino (drage) travne silaže v obroku. Še bolj je to očitno pri poletnih obrokih, pri katerih je glavni vir beljakovin paša, travna silaža pa je posebej pri obroku z večjim poudarkom na cenenosti (WGP II) praktično v celoti izpodrinjena.
Vgrajena kazenska funkcija nam omogoča nadzor nad odstopanjem od postavljenih ciljnih vrednosti. Bolj rigorozno postavljene kazni (v našem primeru višji relativni pomen stroškov; w = 95) v drugem scenariju imajo v obeh sezonah opazen učinek tudi z vidika kakovosti obroka. Čeprav so WGP obroki bolje izravnani, ti cenovno vedno ne odstopajo od LP rešitve (WGP II v zimski sezoni). Na splošno pa lahko pričakujemo dražje obroke pri uporabi WGP (tudi pri močnejšem vplivu kazenske funkcije – scenarij WGP II) kot pri LP in najbrž se nam zdi, da so LP obroki povsem v redu, saj pokrijejo tako potrebe po energiji kot po beljakovinah (so pa slednje pri poletnem obroku v velikem presežku). Ob upoštevanju ostalih odstopanj kot merilom prehranske kakovosti obroka (merjenih s skupno vsoto odstopanj) opazimo očitno razliko, saj smo pri LP zanemarili nekatere prehranske cilje. Še bolj očitno je to pri scenariju WGP I, ko stroški obroka ne igrajo tolikšne vloge (w = 5). Stroški obroka so v naši simulaciji višji za 1 do 12 % (v primerjavi z WGP II), skupno odstopanje pa je nižje za 3 do 27 %. Torej lahko govorimo o iskanju kompromisa med kakovostjo in ekonomičnostjo obroka. Ob tem pa se moramo zavedati, da neizravnani obroki - četudi so posamezne potrebe pokrite - ne bodo dali pričakovane (teoretično izračunane) prireje. To postane toliko bolj problematično, kolikor večje zahteve oz. pričakovanja imamo do svojih živali (npr. dnevna mlečnost nad 30 kg).

4. ZAKLJUČKI

Namen tega prispevka je prikaz enostavnega orodja v obliki elektronske preglednice, ki lahko nudi podporo vsakodnevnim odločitvam na kmetijskem gospodarstvu, v prikazanem primeru pri sestavljanju dnevnih obrokov za krave molznice. Uporabljen pristop, ki temelji na kombinaciji linearnega in tehtanega ciljnega programiranja, podprtega s kazenskimi funkcijami, se je izkazal za uporabnega tudi v aplikaciji za končnega uporabnika. Orodje omogoča posamezniku, da oblikuje ekonomsko učinkovit obrok, ki ne odstopa bistveno od najcenejšega možnega, hkrati pa zmanjšuje tveganje, da ta ne bo izravnan, kar je velika pomanjkljivost praktične uporabe LP pristopa. Z zgrajenim orodjem lahko obroke dodatno izboljšamo z nastavljanjem parametrov vgrajene kazenske funkcije za posamezne elemente krmnega obroka. V analiziranem primeru se je to posebej izkazalo pri poletnem obroku, pri katerem je LP rešitev vsebovala kar 39 % presežek beljakovin, kar lahko pomembno poslabša zdravstveni z njim pa tudi proizvodni status živali.
Čeprav so rešitve tehtanega ciljnega programa praviloma nekoliko dražje kot tiste dobljene s pomočjo klasičnega LP, pa lahko stroškovno učinkovitost sestavljenih obrokov izboljšamo na več načinov. Presežki v obrokih, dobljeni z LP, prav gotovo niso zastonj in imajo vpliv na prirejo (dnevno mlečnost), po drugi strani vplivajo tudi na dobrobit živali (njihovo dodatno obremenitev), zaradi dodatnega izločanja odvečnih hranil in povečanja izločanja toplogrednih vplivov pa imajo tudi negativen učinek na okolje (Brink s sod., 2001). Gre pa za področja, ki še niso dovolj raziskana in je te učinke težko kvantitativno ovrednotiti. Vse to kliče po nadaljnjem delu na tem področju, ki lahko pripelje do novega pogleda na družbeno najbolj sprejemljiv sistem prireje mleka, saj danes praviloma konkurenčnost v prireji mleka določajo le zasebni ekonomski učinki, družbeni pa so v pretežni meri še vedno zanemarjeni.

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