PIEteR: a field specific bio-economic production model for decision support in sugar beet growing

A.B. Smit

Stellingen

1. Kennis over de teelt van (zelfs intensief onderzochte) gewassen blijkt veelal onvoldoende voor een kwantitatief simulatiemodel.
   Dit proefschrift.

2. De suiker- en wortelopbrengsten van suikerbiet zijn veel beter voorspelbaar dan hun quotiënt, het suikergehalte.
   Dit proefschrift.

3. Bij suikerbiet treedt bij de huidige rassen geen interactie op tussen plantaantal en N-bemesting ten aanzien van opbrengst, kwaliteit en uitbetaling.
   Dit proefschrift.

4. Een extra N-gift aan suikerbiet in juni of juli ter verbetering van de kleur van het gewas is slechts 'ogentroost'.
   L.J.P. Kupers (mondelinge mededeling).

5. De relatie tussen het vochtgehalte van de grond en de hoeveelheid grondtarra bij de bietenoogst is onvoldoende bekend en wordt zelfs door sommigen afwezig geacht.

6. Het saldo na aftrek van variabele kosten is voor suikerbiet in het algemeen lager dan voor poot- en consumptieaardappelen, maar als ook de kosten van arbeid, werktuigen en loonwerk in rekening worden gebracht heeft suikerbiet de hoogste rendabiliteit.
   Dit proefschrift.

7. Uitstel van de oogstdatum wordt bij overschrijding van het suikerquotum minder aantrekkelijk, omdat de risico's van hogere tarragehaltes, van structuurbederf en van vorstschade aan ongeoogste bieten dan eerder de afnemende meerproduktie van wortel en suiker gaan overtreffen in waarde.
   Dit proefschrift.

8. Het leerproces dat boeren en tuinders doormaken bij het gebruik van teeltbegeleidingsmodellen is belangrijker dan de exacte uitkomsten van voorspellingen met behulp van deze modellen.

9. The more detailed model is often only accessible to the modeller himself, and even he may lose control.
*C.J.T. Spitters, 1990. Crop growth models: their usefulness and limitations. Acta Horticulturae **267**, 349-368.*

10. De aanstelling van een centrale databankbeheerder binnen Kennis Centrum Wageningen zou de toegankelijkheid van uniforme, goed gedocumenteerde databestanden met experimentele gegevens in ruime zin bevorderen.

11. Een groot voordeel van het AIO-schap is, dat er geen onduidelijkheid bestaat of en wanneer de aanstelling eindigt.

12. Het verheffen van de ratio tot hoogste norm is een vorm van geloof.

13. Een Smit heeft dikwijls meerdere ijzers in het vuur.

Stellingen behorend bij:

'PIEteR: a field specific bio-economic production model for decision support in sugar beet growing'

A.B. Smit
Wageningen, 8 november 1996.

PIEteR:

a field specific bio-economic production model for decision support in sugar beet growing

Promotoren: dr. ir. P.C. Struik
Hoogleraar in de Gewas- en Graslandkunde

dr. ir. J.A. Renkema
Hoogleraar in de Agrarische Bedrijfseconomie

Co-promotor: dr. ir. J.H. van Niejenhuis
Universitair hoofddocent van de vakgroep Agrarische Bedrijfseconomie

A.B. Smit

PIEteR: a field specific bio-economic production model for decision support in sugar beet growing

Proefschrift

ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van de Landbouwuniversiteit Wageningen,
dr. C.M. Karssen,
in het openbaar te verdedigen
op vrijdag 8 november 1996
des namiddags om half twee in de Aula.

Omslag: J.R. Ruisch

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Smit, A.B.

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ISBN: 90-5485-590-8

Keywords: *Beta vulgaris* L., decision support, gross margin, harvest date, nitrogen fertilization, plant density, profit, resowing, simulation model, sugar beet

Abstract

Smit, A.B., 1996. PIEteR: a field specific bio-economic production model for decision support in sugar beet growing.

To support decisions in sugar beet growing, a model, PIEteR, was developed. It simulates growth and production of the crop in a field specific way, making a tailor-made approach in decision taking possible.

PIEteR is based on causal regression analysis of Dutch data of mostly experimental sugar beet fields. Its prototype, which only simulated root and sugar yields, was selected through a test on the performance of four models and extended with a number of parameters: sugar content, (K + Na) and α-amino-N contents, extractability index, tare content, operating receipts (a measure for gross returns), and amounts of leaves and nitrogen in leaves and crowns after harvest. Growth and production rates are corrected by a water balance module.

The effects of plant density, nitrogen availability and harvest date were modelled and included in PIEteR, thus improving its applicability and the accuracy of the predictions. The profitability of resowing after a poor crop establishment was studied and critical plant densities were given for several combinations of sowing and resowing dates. The profitability of a delay in harvest depends to a large extent on the question whether the sugar yield has exceeded the sugar quota level or not. A method to allocate equipment costs to crops, making tactical decisions on sugar beet area possible, was described and included in PIEteR.

Validation of PIEteR on a set of commercial and experimental sugar beet fields showed average prediction errors for root and sugar yields and financial returns per ha of 12%, 13% and 13%, respectively, and the variances accounted for were 52%, 51% and 50%, respectively. A major part of the prediction errors was caused by the prediction error of the sugar content and by the use of average regional instead of local yield and quality levels.

Improvements on PIEteR can contribute to successful use in practical applications, such as: 1) decision support at farm and field level; 2) industrial campaign planning; 3) yield gap analysis; 4) analysis of new cropping techniques, new cultivars, etc. Further research on the prediction of local levels of output parameters seems to be the most important option for improvement of PIEteR, followed by addition of modules for weeds, diseases and pests, cultivars and preceding crops.

Keywords: *Beta vulgaris* L., decision support, gross margin, harvest date, nitrogen fertilization, plant density, profit, resowing, simulation model, sowing date, sugar beet

PhD-thesis, Wageningen Agricultural University, Department of Farm Management, Hollandseweg 1, 6706 KN Wageningen, and Department of Agronomy, Haarweg 333, 6709 RZ Wageningen, The Netherlands.

Voorwoord

In dit proefschrift zijn de resultaten van een project over de modellering van het gewas suikerbieten uitgekristalliseerd. Het project werd al in 1987 opgestart. Ir. Teun Biemond, destijds docent bij de vakgroep Agrarische Bedrijfseconomie van de Landbouwuniversiteit Wageningen (LUW), was één van de belangrijkste initiatiefnemers en werd in de beginjaren bijgestaan door met name dr. ir. Kees Spitters (Stichting voor Planten-veredeling (SVP), Wageningen) en ing. Teun Schiphouwer (Suiker Unie (tegenwoordig: Cosun), Breda), waarbij ook studenten een aandeel leverden. Van de laatste moet met name Arry Verhage genoemd worden; hij ontwierp een waterbalansmodule voor de bodem, die met aanpassingen een belangrijk deel van het model PIEteR zou gaan uitmaken, zeker als gemeten wordt in aantal programmeerregels.

Teun Biemond vertrok in 1990 naar een betrekking in het bedrijfsleven. Het project werd vervolgens herschreven en financieel voor een belangrijk deel geadopteerd door het Instituut voor Rationele Suikerproduktie (IRS) in Bergen op Zoom. Zodoende kon ondergetekende per 15 januari 1992 als assistent in opleiding (AIO) aangesteld worden bij de LUW-vakgroepen Agronomie (toen nog: Landbouwplantenteelt en Graslandkunde) en Agrarische Bedrijfseconomie. Ik dank alle betrokken partijen voor het in mij gestelde vertrouwen en de beschikbare middelen.

Het project bestond globaal gezien uit een integratie van drie vakgebieden, waarbij het gewas suikerbieten centraal stond: 1) de teelt van akkerbouwgewassen, 2) de economie van het agrarische bedrijf, en 3) de systeemanalyse en computersimulatie. Het eerste deelgebied omvatte de studie van de invloed van verschillende factoren op de groei en productie van suikerbieten. Sommige van die factoren zijn door de teler niet te beïnvloeden, met name weersomstandigheden, andere wel, zoals N-gift en plantaantal, waarbij de exacte invloed afhankelijk is van bodem- en weersomstandigheden. Het tweede gebied betrof: a) de besluitvorming van de akkerbouwer bij de teelt van suikerbieten, zowel op gewas- als op rotatieniveau, b) afweging van zowel kosten als financiële opbrengsten van de teelt en van specifieke teeltmaatregelen, en c) risico-analyse bij bepaalde beslissingen waarvan het effect niet bij voorbaat vast staat. Het derde deelgebied hield in het opnemen van teeltkundige en bedrijfseconomische relaties in een model dat met een personal of main frame computer doorgerekend kon worden. Hiervoor was onder andere kennis van een aantal programmeertalen vereist. Vooral op het laatste gebied, dat van de systeemanalyse en computersimulatie, maar ook in het tweede, met name op het terrein van risico-analyse, zijn de mogelijkheden benut om als AIO ontbrekende kennis en vaardigheden aan te vullen middels het onderwijs- en begeleidingsplan.

Een wezenlijk onderdeel van een AIO-project is het formuleren van een nieuw concept. Al gaandeweg moet je ontdekken hoe je het gestelde doel, in mijn geval beslissingsondersteuning in de suikerbietenteelt, kan bereiken en welke stappen nodig zijn om zover te komen. Denk-, zoek- en praatwerk zijn dan ook belangrijke aspecten. Het geheel is niet een voorgekauwd menu, maar een zoektocht naar mogelijkheden, gegevens, methoden, enz. Succes is dan ook niet bij voorbaat verzekerd; gebrek aan bruikbare gegevens of aan tijd om geschikte methoden en data te ontwikkelen kunnen in principe het werk op essentiële punten frustreren. Dit is gelukkig niet gebeurd, mede door de betrokkenheid van een groot aantal mensen. Een aantal van hen noem ik hier bij name.

Een zeer centrale rol is gespeeld door de Projectgroep 'Bio-economisch produktiemodel suikerbieten', bestaande uit de promotoren, prof. dr. ir. J.A. Renkema en prof. dr. ir. P.C. Struik, de copromotor, dr. ir. J.H. van Niejenhuis, en een tweetal deskundigen van het IRS, te weten ir. M.A. van der Beek (voormalig Adjunct-directeur/Hoofd Teeltzaken) en ing. P. Wilting (Bemestingsdeskudige). Professor Renkema, mede door uw bijdrage is het gelukt om het proefschrift tot één geheel te maken, want u had steeds de rode draad én het overzicht sterk voor ogen. Paul Struik, je was een kritisch en enthousiast leermeester, zodat mijn academische vaardigheden in de afgelopen jaren flink konden toenemen. Jan van Niejenhuis, je inbreng op het bedrijfseconomische vlak en je dagelijkse begeleiding, ook in de zin van organisatie, financiën en dergelijke heb ik zeer gewaardeerd, temeer daar het samenwerkingsverband tussen twee vakgroepen en een extern instituut de nodige afstemming nodig maakte. Heer van der Beek, uw kennis wordt wel eens als 'encyclopedisch' bestempeld; ik ben dan ook blij dat ik van uw inzichten gebruik mocht maken. Peter Wilting, je maakte mij als Wageninger meer dan eens duidelijk, dat vuistregels en principes in de praktijk wel eens aan uitzonderingen onderhevig zijn, zodat een modelbenadering wel eens te generaliserend kan zijn. Bedankt voor je inbreng!

De Projectgroep kwam een keer per drie maanden bijeen en beoordeelde dan mijn bevindingen, plannen en voortgang. Ook tussendoor was er veelvuldig bilateraal contact, waarin ik een grote mate van medwerking heb ervaren. Nogmaals: hartelijk dank! De eerste bijeenkomsten beleefde ik destijds als een soort examen, maar al snel kreeg het gevoel van 'team work' de overhand, wat wel aangeeft dat er een goede, opbouwende sfeer in de groep was. Er was duidelijk een enthousiaste betrokkenheid bij het onderwerp en de uitwerking er van.

Naast de Projectgroep was er een Begeleidingsgroep, die een keer per half jaar bijeen kwam. Deze groep hield zich voornamelijk met de hoofdlijnen van het onderzoek bezig, de richting en de voortgang. In deze groep zaten de leden van de Projectgroep (uitgezonderd de heer Van der Beek), aangevuld met ing. Teun Schiphouwer (Suiker Unie), ing. Hein Antonissen (CSM Suiker, Diemen), Ir. Kees Westerdijk (Proefstation voor de Akkerbouw en de Groenteteelt in de Vollegrond (PAGV), Lelystad) en Dick Zoeteman (akkerbouwer in Oostelijk Flevoland). De groep werd voorgezeten door de directeur van het IRS; dat was in eerste instantie ir. D. Hoogerkamp en, na diens afscheid (op 1 juli 1994) dr. ir. Frans Tijink. De Begeleidingsgroep leverde een nuttige aanvulling op het inhoudelijke werk van de Projectgroep, omdat de vijf niet-Projectgroepleden een frisse en kritische kijk op het project hadden, gebaseerd op een grote kennis van de praktijk. Daarnaast was er steeds de mogelijkheid om door bilateraal overleg bepaalde zaken scherper in beeld te krijgen. Allen hartelijk dank voor de inzet en betrokkenheid!

Toen mijn AIO-project van start ging was er al het één en ander aan voorwerk gedaan. Naast de reeds genoemde inbreng van Teun Biemond, Kees Spitters, Teun Schiphouwer en Arry Verhage, moet ook het programmeerwerk van ir. Erik Greve (destijds werkzaam bij Suiker Unie) genoemd worden. Door het inbedden van de gevonden basisrelaties in een Turbo Pascal-shell en de begeleiding bij het omzetten naar de Wageningse werkomgeving heb je me prima op weg geholpen; dankjewel! Ing. Harry Haverkamp van de vakgroep Agrarische Bedrijfseconomie heeft me later geholpen om het model geschikt te maken voor het draaien van reeksen percelen achter elkaar, waarvoor dank!

Op computer- en systeembeheergebied moet ook Hans Romberg van de vakgroep Agronomie genoemd worden. Tijdens de drie jaren die ik verbleef op deze vakgroep heeft hij steeds met grote inzet de computertechnische aspecten behartigd, zoals computerconfiguratie, printer- en e-mailgebruik en dergelijke. Ook meewerkende studenten konden profiteren van jouw bekwaamheden, Hans. Dankjewel! Op de vakgroep Agrarische Bedrijfseconomie, waar ik 1,5 jaar aan het project werkte, was ing. Jouke Oenema verantwoordelijk voor deze taak. Daarnaast heb je een aanzienlijke bijdrage geleverd aan mijn pogingen op de VAX-mainframe van de Landbouwuniversiteit enorme bestanden te bewerken met het pakker SAS, met name bij schattingen van coëfficiënten in tamelijk ingewikkelde niet-lineaire relaties. Ook ir. Gert Lokhorst, die destijds bij de afdeling Informatisering en Datacommunicatie van de LUW werkte, wil ik van harte bedanken toen om allerlei redenen overgeschakeld moest worden naar de Alpha-mainframe, die hele nachten voor mij moest rekenen om tot optimale schattingen te komen. Gelukkig kon deze machine dit werk doen zonder de betrokkenen wakker te houden!

Overigens is niet automatisch op het werk van Teun Biemond voortgebouwd, dat klaar lag in de vorm van een prototype van PIEteR. In de beginfase zijn ook andere modellen getest. Graag spreek ik een woord van dank uit naar mevr. dr. ir. Hilde Vandendriessche (Bodemkundig Instituut van België, Leuven-Heverlee), die op 28 september 1995 promoveerde op haar eigen suikerbietenmodel, SUBEMOpo. Zij was bereid om een prototype van haar model los te laten op een set testgegevens. Hetzelfde werd gedaan met de Wageningse modellen LINTUL en SUCROS. Het eerste model werd beschikbaar gesteld door mevr. Gonnie van Laar van de Vakgroep Theoretische Produktie Ecologie (LUW) en het tweede door ing. Willem Stol van het AB-DLO (Instituut voor Agrobiologisch en Bodemvruchtbaarheidsonderzoek, Wageningen). Laatstgenoemde speelde een belangrijke rol in de ontwikkeling van een versie van SUCROS met waterlimitering voor suikerbieten. Daardoor werd de test nog completer. Ook voorzag je me van talloze weerfiles, die als input moesten dienen voor de verschillende modellen. Dankjewel, Willem!

Hulp ontving ik ook van het Proefbedrijf van de voormalige vakgroep Landbouwplantenteelt en Graslandkunde; dit bedrijf is later opgegaan in UNIFARM, dat brede faciliteiten biedt voor plant- en gewaskundige experimenten. Allen die geholpen hebben bij de in 1993 uitgevoerde kiem- en veldproeven, wil ik hartelijk bedanken voor de inzet. Weliswaar hebben deze proeven geen 'wetenschappelijke doorbraak' opgeleverd, maar de resultaten waren toch bruikbaar bij de modellering van verschillende stadia van de groei en produktie van het gewas en bij de invloed van stikstofbemesting hierop. Overigens prijs ik mezelf gelukkig, dat ik door deze experimenten de suikerbiet langdurig en intensief van dichtbij kon meemaken. Een gewas simuleren zonder letterlijk met je neus tussen de bladeren en de wortels te hebben gezeten lijkt mij toch eigenlijk niet goed mogelijk. Je moet als het ware gevoel voor het gewas krijgen en daarvoor waren de experimenten een uitstekend middel. Hartelijk dank, UNIFARM-ers, en ook een woord van dank aan dr. ing. Klaas Scholte, die adviezen gaf bij de opzet van de veldproef. Op statistisch gebied in het algemeen zijn ook de adviezen van ir. Klaas Metselaar van de Groep Landbouw Wiskunde (GLW-DLO, Wageningen) zeer gewaardeerd.

Om een model met verschillende aspecten te kunnen ontwikkelen was uiteraard veel meer informatie nodig dan uit de eigen experimenten af te leiden viel. Verschillende organisaties leverden onderzoeksgegevens aan, in veel gevallen via publikaties, maar soms was er ook de mogelijkheid om onderliggend basismateriaal te gebruiken. Graag noem ik opnieuw het IRS, waar in het bijzonder de heren Leo Withagen en ir. Toon Huijbregts een veelheid aan gegevens aandroegen, en het Proefstation voor de Akkerbouw en de Groenteteelt in de Vollegrond (PAGV, Lelystad), waar ir. Frank Wijnands en ing. Pauline van Asperen inzage gaven in de resultaten van Innovatiebedrijven; ing. Henk Floot, onderzoeker op een aantal regionale onderzoekscentra (ROC's) in Noord-Nederland, voorzag mij van de originele data van een langjarige vruchtwisselingsproef op Feddemaheerd. Bovendien leverden hij en andere ROC-onderzoekers semi-praktijkgegevens, waarop het model getest kon worden. Allen hartelijk dank voor de medewerking!

In de afgelopen 4,5 jaren deden tien studenten een afstudeervak bij mij: Jaap Mosselman, Kasper de Graaf, Jan Bartelds, Mike Jacobs, Frank Inghels, Benjamin Refuge, André de Swart, Gerard Muijs, Henk de Vries en Jeroen van Soesbergen. Zij droegen daarmee direct of indirect bij aan het resultaat van dit proefschrift. Ir. Joost Hooijman deed een Na-doctoraal Onderzoeksproject (NOP); tijdens dit project vond hij een 'echte' baan, zodat hij helaas zijn werk niet meer als publikatie kon uitdragen. Desondanks was het nuttig enig inzicht in de werking van de wereldsuikermarkt en de rol van de Europese Unie daarin te verkrijgen.

In internationaal verband heeft het Internationale Suikerbieteninstituut (I.I.R.B.) in Brussel een belangrijke rol gespeeld bij de gedachtenvorming. Behalve in de vorm van congressen en publikaties, bleek vooral de werkgroep 'Modelling' van de afdeling 'Plant and Soil' een nuttig forum voor ontwikkeling en toetsing van ideeën over de modellering van verschillende aspecten van het gewas. I would like to address a special word of thanks to dr. Keith Jaggard (IACR Broom's Barn, Bury St Edmunds, Great Britain), chairman and secretary of the I.I.R.B.-modellers group, for your efforts and enthousiasm to organize a meeting every two years. Auch möchte ich prof. dr. B. Märländer und seinen Mitarbeitern, im besondern dr. Heinz-Josef Koch und dr. Achim Röver, danken für Ihre Gastfreundschaft auf dem Institut für Zuckerrübenforschung in Göttingen, Deutschland, und die gute Diskussionen die wir hatten, Januar 1996. Naast een lezing op het 'grote' jaarlijkse congres van het I.I.R.B. was ik in de gelegenheid om aan het begin van het AIO-project, halverwege en aan het einde mijn plannen en resultaten in de werkgroep naar voren te brengen, hetgeen in meerdere opzichten erg nuttig was.

Het geeft mij voldoening en dankbaarheid om een proefschrift over een interessant gewas tot een goed einde te mogen brengen. Maar als de inhoud dan voor kennisgeving wordt aangenomen en het proefschrift verder ongebruikt in de kast verdwijnt, is dat erg jammer. Daarom ben ik blij dat het IRS de verzamelde kennis verder uitwerkt in het oogstprognosemodel SUMO, dat een rol speelt bij de campagneplanning van de suikerindustrie. De samenwerking met Leo Withagen van het IRS, ir. Bernard van Raaij en anderen van Q-Ray Agrimathica in Veenendaal en de heren van de suikerindustrie (Teun Schiphouwer en Hein Antonissen) is goed bevallen. Wellicht worden er nog meer toepassingen voor de praktijk gerealiseerd in de toekomst, waarbij gedacht moet worden aan versterking van voorlichting en prognose, zowel op industrie- als op bedrijfs- en perceelsniveau. Ik ben Frans Tijink, directeur van het IRS, erkentelijk voor zijn visie en inzet om het verrichte AIO-werk praktisch toegankelijk te maken.

Vele collega's aan de LUW hebben door hun aanwezigheid en velerlei tips en raadgevingen bijgedragen aan het proefschrift. In het bijzonder wil ik mijn kamergenoten op Agronomie en Agrarische Bedrijfseconomie, respectievelijk dr. ir. Henk Biemond en ir. John Hopman bedanken voor hun betrokkenheid en bijdragen. Voor Henk was het wellicht bijzonder dat hij van dichtbij meemaakte hoe het werk van zijn neef, Teun, verder uitgewerkt werd. Jammer dat je zelf niet meer de kans hebt gehad om je 'eigen' gewasssen (aardappelen en vollgegrondsgroenten) te modelleren. Met beide kamergenoten kon ik behalve over landbouwkundige zaken ook regelmatig over het geloof in de Here Jezus Christus spreken, al stonden jullie daar wel zeer verschillend tegenover. Voor mij is Hij de belangrijkste in het leven en het was goed om iets van het geloof in Hem met jullie te kunnen delen! Ook ben ik blij dat jullie mijn paranimfen willen zijn.

Van de collega's wil ik ook de secretaresses en beheersassistenten noemen; door de samenwerking tussen twee vakgroepen, de verbinding met het IRS en mijn verhuizingen van de ene naar de andere locatie hadden jullie geen eenvoudige taak. Maar het ziet er naar uit, dat alles rond komt: dank!

In de privésfeer wil ik mijn vele vrienden noemen, van wie een aantal ook nog deel uitmaakt van dezelfde kerkelijke gemeenschap. In het bijzonder wil ik Jan Ruisch bedanken, met wie ik al jaren met vreugde samen mag werken in Evangeliegemeente Salem. Uit jouw kunstenaarshanden is een prachtige omslag voortgekomen. Hartelijk dank!

Zonder vriendschap was het niet gelukt. Zonder mijn ouders was het ook niet gelukt. Aan u heb ik veel te danken. Zonder jarenlange (op)voeding was ik nooit zo ver gekomen als vandaag het geval is; in het bijzonder ben ik dankbaar voor het boerenvak dat u mij geleerd hebt. Dat is iets wat ik niet meer kwijt raak, ook al blijf ik waarschijnlijk m'n hele leven 'boukje-boer'! Bedankt voor alle adviezen en praktische hulp!

Mede door toedoen van mijn ouders heb ik ook de Here God vroeg in mijn leven mogen leren kennen en verlossing van zonde, schuld en oordeel door Zijn Zoon, de Here Jezus Christus ontvangen. Ik ben mijn Schepper dankbaar voor biddende ouders met een waarachtig geloofsleven. Daarom kan ik het ook niet laten om God Zelf dank en eer te brengen voor de kracht, het verstand en de gezondheid die Hij gegeven heeft om dit promotiewerk te voltooien. Kwetsbaar en tijdelijk is de mens en zijn werk is onvolmaakt. Maar door Uw genade mocht ik dit onderzoek voor U doen en daardoor krijgt het eeuwigheidswaarde. Uw liefde en trouw gaan al het aardse verre te boven!

Bert Smit
Wageningen, september 1996.

Contents

Account

In this PhD-thesis, 9 papers are included that have been published, accepted or submitted for publication in international scientific journals or refereed proceedings of an international congress. Permission was granted to include these in the thesis, which is gratefully acknowledged.

Chapter 1:

Smit, A.B., J.H. van Niejenhuis & P.C. Struik, 1994. Introduction to a bio-economic production model for sugar beet growing. In: P.C. Struik, W.J. Vredenberg, J.A. Renkema and J.E. Parlevliet (eds.). Plant production on the threshold of a new century. Proceedings of the International Conference at the occasion of the 75th Anniversary of the Wageningen Agricultural University, Wageningen, The Netherlands, held June 28 - July 1, 1993. Developments in plant and soil sciences, 61. Dordrecht/Boston/London, Kluwer Academic Publishers: 115-122.

Chapter 3:

Smit, A.B. & P.C. Struik, 1995. The first step towards a decision support system for sugar beet growing: selection of a basic model. *Journal of Agronomy and Crop Science* **175**, 213-220.

Chapter 4:

Smit, A.B. & P.C. Struik, 1995. PIEteR: a field-specific production model for sugar beet growing. *Journal of Agronomy and Crop Science* **175**, 335-348.

Chapter 5:

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1995. Modelling the influence of plant density on yield, sugar content and extractability of sugar beet. In: Proceedings of the 58th IIRB-congress, 19-22 June 1995, France. IIRB, Brussels: 413-424.

Chapter 6:

Smit, A.B., P.C. Struik, J.H. van Niejenhuis & J.A. Renkema, 1996. Critical plant densities for resowing. *Journal of Agronomy and Crop Science* (in press).

Chapter 7:

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1995. Nitrogen effects in sugar beet growing. A module for decision support. *Netherlands Journal of Agricultural Science* **43**, 4, 391-408.

Chapter 8:

Smit, A.B., P.C. Struik & J.H. Van Niejenhuis, 1996. Prediction of various effects of harvest date in sugar beet growing. *Journal of Agricultural Engineering Research* (submitted).

Chapter 9:

Smit, A.B., G.J.W. Muijs, P.C. Struik & J.H. van Niejenhuis, 1996. Evaluation of a model for sugar beet production by comparing field measurements with computer predictions. *Computers and Electronics in Agriculture* (accepted).

Chapter 10:

Smit, A.B., J.H. van Niejenhuis & J.A. Renkema, 1996. A farm economic module for tactical decisions on sugar beet area. *Netherlands Journal of Agricultural Science* (submitted).

Notes:

1 References should be made as much as possible to the original publications.

2 Minor changes have been made in the original publications to standardize presentation in the thesis.

3 In the original publications of Chapters 3 and 4, the term *lutum* was incorrectly defined as 'the fraction of the soil texture with particles smaller than 16 μm (silt and clay)'. This should have been: 'smaller than 2 μm (clay)'. The corrections have been included in the thesis.

4 The water balance reduction factor, given in Chapter 4, equation 1, is not the direct correction factor for the growth or production rates; the adapted correction factor is defined as:

$$rf[day]_{adap} = 1 - 0.5 * (1 - \sqrt{(rf[day])}) \tag{1}$$

in which:

$rf[day]_{adap}$	=	adapted reduction factor for suboptimal soil moisture content	[-]
$rf[day]$	=	original reduction factor for suboptimal soil moisture content	[-]

For example, when $rf[day] = 0.81$, then $rf[day]_{adap} = 0.95$.

CHAPTER 1

Introduction to a bio-economic production model for sugar beet growing

A.B. Smit, J.H. van Niejenhuis & P.C. Struik

Abstract
Yield prediction is a basic tool for practical purposes in sugar beet growing. Connected with an economic module, a crop model can serve as a basis for decision support at field level. PIEteR as such is a bio-economic model, mainly focusing on nitrogen fertilization, plant density and harvest date. Its main component is a crop growth model, that simulates crop responses to weather, soil factors and growers' decisions. Its input and (future) output make PIEteR a useful basis for decision support. Its potential for accurate predictions will be tested and compared with other models. If PIEteR will prove to be the most accurate and useful model, it will be developed further, thus enabling improvements in the quality of the growers' decisions.

Keywords: sugar beet, decision support system, expert system, growth model, harvest planning, yield prediction, bio-economic model, black box, location specific

1. Introduction

Yield prediction is a scientific challenge and a practical necessity. In science it is a way to obtain more insight in plant and crop processes. Yield prediction is also a basic tool for practical purposes in the sugar industry and sugar beet growing (Withagen, 1989), facilitating:

1 logistic planning of mainly sugar beet transportation and production, storage and sale of sugar in sugar industry (Crals and Stinglhamber, 1992);
2 planning at farm level.

Yield prediction to support planning in the sugar industry has been far more widely applied than decision support at individual farm level (Sperlingsson and Choppin de Janvry, 1992). Crop yield can be predicted by two types of models (Burke, 1992):

1 mechanistic or dynamic growth models, simulating the processes occurring in crop-weather interactions;
2 regression or black box models, based on empirical relationships and using meteorological records and crop yield data from the past.

The first approach leads to a more complex model than the second. It has a wider range of application, especially as a research tool. A dynamic model may predict yields better than a regression model, but requires more information input. If this information is not available, the regression model may be the best option (Burke, 1992; Seligman, 1990).

A new field in crop modelling is the combination of crop growth and economic models. Economic factors never interact directly with plant growth, but crop models and economics can be combined to support farm management (Penning de Vries, 1990). In general, only a few crop models for farm management are successful, even when they have been especially tailored for use by farmers or extension personnel (Seligman, 1990). In the period 1987 - 1990 Biemond *et al.* (1989) began the development of PIEteR [1], a bio-economic model as a basis for decision support in sugar beet growing. In 1992, this research, still in its infant stage, was evaluated and re-started under the new project title **'The development of a location specific bio-economic production model for tactical decision support in sugar beet growing, with special reference to yield, quality and environment'**. It focuses on tactical and semi-operational decisions in sugar beet growing at farm level.

Tactical and semi-operational decisions have to be made by the farmer before or during the growing season. Thus, repeated operational decisions, such as those on weed removal, are excluded. The most important decisions in our model are nitrogen supply, plant density and harvest date. Other tactical and semi-operational decisions are those on tillage, seed bed preparation, choice of variety, sowing time, sown area (related to permitted yield quota), resowing, and harvest method. In the following we discuss decision support in sugar beet growing (2) and describe the current status of PIEteR (3).

2. Decision support in sugar beet growing

2.1. Expert systems and decision support

In the following an existing expert system for sugar beet growing is discussed and the need to develop a decision support system is explained and illustrated.

BETA is an expert system for sugar beet growing, developed by the Research Station for Arable Farming and Field Production of Vegetables (PAGV) and others (Kemp Hakkert, 1992). BETA assists farmers to make improved decisions on choice of variety, crop protection etc. It uses previous observations on root and sugar yield of varieties that were grown on different fields at the farm over several seasons in recent years. Actual information on sowing

[1] PIEteR means: '**P**roduction model for sugar beet, including **I**nteractions between **E**nvironment and growing decisions, and their influence on the quantitative, qualitative and financial **R**esult'.

date, plant density and growing stage is necessary for advice on resowing and herbicide application to use just a few examples. BETA presents a list of recipes, such as 'If this occurs, then you can choose between the following options: ...'.

For some decisions the 'recipe method' is not sufficient. More location specific information is needed on the actual growth and production of the crop, to predict for example the influence of harvest date on yield and profit in a specific combination of weather, soil and previous treatments. This was behind the initiative in 1987 to develop PIEteR, a location specific bio-economic production model as a basis for decision support.

PIEteR is still in an early stage of development. In future it should be able to analyse a combination of different sets of input that, 'processed' by a system of processes and interactions, will offer agronomic, ecological and farm economic predictions. This output will significantly increase farmers' ability to reach optimal decisions in given circumstances.

PIEteR's inputs requirements include:

1 meteorological data (temperature, radiation, rainfall);
2 soil data, which make the model explicitly location specific (contents of silt and organic matter);
3 growers' decisions (sowing date, plant density, harvest date);
4 the payment system for sugar beet (based on harvest date, yield and quality). This system takes into account E.U. price policy, world market prices of sugar and the penalties that have to be paid for dirt tare;

PIEteR's outputs present the expected value of several parameters at different dates (in percentage, kg or guilders per ha):

1 root and sugar yield;
2 sugar content and extractability;
3 dirt tare;
4 remaining nitrogen in the soil, after harvest;
5 economic result.

In order to produce output from a given input, quantitative knowledge is required on:

1 the crop's response to the effects of meteorological and soil data and growers' decisions;
2 the remaining processes in the soil, that determine the losses of nitrogen, especially by leaching.

Thus, different disciplines are integrated in this project, especially crop ecology, soil science and farm economics. Moreover, different process levels are integrated: crop, field, farm and sector level. Growers' decisions increasingly have to deal with all these levels. In arable farming there is a growing need to take into account not only crop development, but to optimize farm planning as a whole and to be aware of what is happening on meso- and macro-scale in agriculture.

2.2. Harvest time as a point for illustration

As stated above, the most important decisions in PIEteR are nitrogen supply, plant density and harvest date. The first two will not be discussed here, but the main principle is the same as for the third: harvest and delivery time of sugar beets.

The sugar industry focuses on optimal use of processing machinery and labour during the campaign. Since processing during Christmas would induce high labour costs, the campaign should be finished before December 25th. On the other hand, the campaign should start as late as possible, since early delivery has to be met with industrial subsidies to compensate yield losses. Based on national and regional yield predictions in August the sugar industry makes a planning for daily amounts of beets to be processed.

In order to fulfil the industrial planning, the company representatives develop a time table for delivery of sugar beets from the farms in the various regions. The individual farmer has some influence on this time table and on the amounts that should be delivered at various dates. To enable him to plan in an efficient and economic way he should know at the beginning of August, which yield of root and sugar he can expect. Later on in the growing season, especially in the months of October and November, it can be helpful to harvest some weeks earlier than delivery date. This would reduce frost risks and possibly the amount of dirt tare and the risk of soil structure damage. The latter results from an increasing precipitation surplus during these months. Before harvest, internal quality may increase over time, i.e. both sugar content and extractability, thus improving the farmer's profit. After harvest, during storage. both will decrease.

The model should therefore predict the influences of a decision to harvest one week later than normal. Depending on the time of year, this could have a positive influence on yield, internal quality and storage losses. On the other hand, dirt tare, frost damage to the crop and soil structure problems could have a negative influence. The net financial effect will be spelt out to farmers using the programme.

3. PIEteR

3.1 Actual state

The actual state of PIEteR is the result of the work of Biemond *et al.* (1989) and Greve (1992). They chose a black box approach, in which causal relationships are described by non-linear equations. The model is dynamic, because it simulates growth and production on a daily basis. It is not mechanistic, since relationships are described only at a high level of integration. The coefficients have been determined by causal regression analysis of data from the Dutch Research Institute for Sugar Beet Growing (IRS) and the sugar industry.

PIEteR exists of a main module to which several submodules are connected. The main module describes growth and production of the crop. Five phases are distinguished. In each of the five, different factors have major influence on the biological processes that take place (Biemond *et al.*, 1989; Houtman, 1992; Schiphouwer, 1992) [2]:

1 The 'emergence phase': the period between sowing and emergence; the length of this period depends mainly on soil temperature.

2 The 'phase of exponential growth': the period between emergence and the so-called 'growth point date' (GPD), the day on which an average root contains 4 gram of sugar (Van der Beek en Kemp Hakkert, 1992) [3]; in this phase growth rate is determined mainly by air temperature.

3 The 'production phase' or 'phase of linear growth': the period after GPD until the end of August/the beginning of September; in this phase dry matter and sugar production depends mainly on radiation.

4 The 'ripening phase' [4]: this period starts at the moment at which growth rate changes from constant to decreasing; the actual growth rate depends on availability of water and nitrogen. There may be redistribution of dry matter; sugar content may increase or decrease. The end of growth will be somewhere between September 15th and October 15th. Temperature, especially night temperature, and radiation play an important role in this phase. The ripening phase ends at harvest.

5 The 'storage phase': the period between harvest and delivery to the sugar factory; temperature is the main factor in this period, influencing respiration rate or inducing frost losses.

The growth module basically estimates GPD and root and sugar yield on the basis of daily values of average air temperature and radiation, respectively. The modules that are connected to the growth module, calculate daily values of a number of other input variables. One of the main variables is a reduction factor that corrects development and production rates for water stress. This stress may be either water surplus or water shortage. The question if and to what extent water stress will occur, is answered using modules that calculate root growth and water balance of the soil.

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[2] In the following, water and nutrients are assumed not to be limiting.

[3] GPD nearly coincides with 'full canopy', which is defined as 'the day on which the first leaves of different rows touch' (Spitters *et al.*, 1990; Van der Beek, IRS, pers. comm., 1992).

[4] Sugar beet is a biennial plant, so that ripening in the meaning of 'ripening of seed' does not occur in the first year (except for bolted plants, perhaps (Smit, 1983)). In the first, vegetative year, ripening can be defined as the development of the plant towards a stable situation, i.e. new leaves do not appear any more and beet yield and sugar content do not change.

At the current state of development PIEteR predicts GPD on a field specific basis and root and sugar production on a regional basis. Emergence day is not yet predicted accurately and no attention is given to the storage phase. Neither have nitrogen fertilization, plant density, internal (sugar content and extractability), external quality (dirt tare) and nitrogen surplus been modelled yet. These will be incorporated in PIEteR during the project.

3.2. Test

Greve (1992) [5] tested PIEteR on data of more than 3000 sugar beet fields in 1991. Regional and national means of GPD, root and sugar yields were presented.

The national prediction of GPD was exactly the same as determined by sampling by the Dutch Research Institute for Sugar Beet Growing (IRS): day 182 (July 1st, which was 89 days after sowing on April 3rd). Regional averages had a maximum deviation of 4 days.

The prediction of the national sugar yield was 10950 kg per ha, which was 70 kg more than the values from IRS-sampling. Regional differences were much higher, ranging from -1650 to +1140 kg per ha.

4. Discussion

PIEteR predicts GPD, fresh root and sugar yield, correcting for suboptimal moisture contents in the soil. It also includes field specific parameters, such as silt and organic matter content. As a consequence, PIEteR may be useful in developing a model as a basis for decision support in sugar beet growing.

In the test, the sugar yield was not predicted so well. Part of the explanation is that the growing season was far from normal in some regions: part of the sugar beet area had to be resown due to frost damage and a wet and cold start (May, June) was followed by a very dry summer. Apparently, the model was not able to cope with such extreme circumstances. The post-season runs for 1992 were much better (H.J. Greve and T. Schiphouwer, pers. comm.).

It was decided that PIEteR and other production models for sugar beets should be compared in order to find the best basic model for the purpose of yield prediction and decision support of sugar beet growing. The main criteria will be prediction accuracy and usefulness at farm level. PIEteR has the advantage that predictions will not require sampling by farmers.

Considerably more research must be carried out before all quantitative relationships may be presented. This is not only true for harvest date, but also for nitrogen level, plant density and other variables. The different influences on yield, quality, environment and farm economic

[5] Greve and Schiphouwer (Suiker Unie Breda) contributed to PIEteR in modelling root and sugar yield per ha. They used regional coefficients from data covering a period of 10 years.

returns should become clear and quantified for every reasonable level of these variables. As an example, data on the exact influence of nitrogen level on sugar content will be incorporated as an important relationship in PIEteR.

Even if all relationships are fully known, then there will still remain a certain amount of uncertainty. Frost risk has already been mentioned. Other weather circumstances cannot be predicted very accurately from one week to the next. Nevertheless, extreme situations and the chance of their occurrence can serve as input for a sensitivity check. In that way, balanced decision making is greatly improved.

In the next century the call for a more economic and environmentally friendly way to produce crops will continue and grow even stronger. We hope that our model, the extended version of PIEteR, will be a good tool to improve the quality of decision making of the sugar beet growers. May it be helpful to match the social and farm economic needs in the 21st century.

5. References

Beek, van der, M.A. & D.J. Kemp Hakkert, 1992. De groei van de suikerbieten tot medio augustus. *Maandblad Suiker Unie* **26**, 12-13.

Biemond, T., H.J. Greve, T. Schiphouwer & A.J. Verhage, 1989. Pieter, semi green-box produktiemodel suikerbieten. Wageningen, WAU, Department of Farm Economics.

Burke, J.I., 1992. A physiological growth model for forecasting sugar beet yield in Ireland. In: Proceedings of the IIRB-Congress, Brussels, 12-13 February 1992: 239-251.

Crals, M.L. & E. Stinglhamber, 1992. Importance des previsions de production dans la gestion d'une sucrerie. In: Proceedings of the IIRB-Congress, Brussels, 12-13 February 1992: 157-168.

Greve, H.J., 1992. Rapport perceelsgericht produktiemodel. Suiker Unie, Breda.

Houtman, H.J., 1992. Bewaring van suikerbieten. In: Artikelen Suikerbieten Informatiedagen 1992, IRS, Bergen op Zoom: 34-38.

Kemp Hakkert, D.J., 1992. BETA, a crop management system for sugar beet: development and experiences. In: Proceedings of the IIRB-Congress, Brussels, 12-13 February 1992: 53-62.

Penning de Vries, F.W.T., 1990. Can crop models contain economic factors?. In: R. Rabbinge, J. Goudriaan, H. van Keulen, F.W.T. Penning de Vries & H.H. van Laar (eds.). Theoretical Production Ecology: reflections and prospects. Wageningen, Pudoc, Simulation Monographs 34: Chapter 6, 89-103.

Schiphouwer, T., 1992. Invloed klimatologische factoren op de groei van suikerbieten. Suiker Unie, Breda.

Seligman, N.G., 1990. The crop model record: promise or poor show? In: R. Rabbinge, J. Goudriaan, H. van Keulen, F.W.T. Penning de Vries & H.H. van Laar (eds.). Theoretical Production Ecology: reflections and prospects. Wageningen, Pudoc, Simulation Monographs 34: Chapter 14, 249-263.

Smit, A.L., 1983. Influence of external factors on growth and development of sugarbeet. Wageningen, WAU, PhD-thesis, 109 pp.

Sperlingsson, C. & E. Choppin de Janvry, 1992. Survey of information and communication systems in European sugar beet growing. In: Proceedings of the IIRB-Congress, Brussels, 12-13 February 1992. Brussels, IIRB: 1-15.

Spitters, C.J.T., B. Kiewiet & T. Schiphouwer, 1990. A weather-based yield-forecasting model for sugar beet. *Netherlands Journal of Agricultural Science* **38**, 731-735.

Withagen, L.M., 1989. Noodzaak van een groeimodel: produktieschattingen en ondersteuning van teeltbeslissingen. In: T. Biemond (ed.). Produktiemodel suikerbieten. Rapportage workshop 3 mei 1989. Wageningen, WAU, Department of Farm Economics: 4-5 and 29-38.

CHAPTER 2

Decision making in sugar beet production at crop, cropping system and farm level

2.1 Introduction

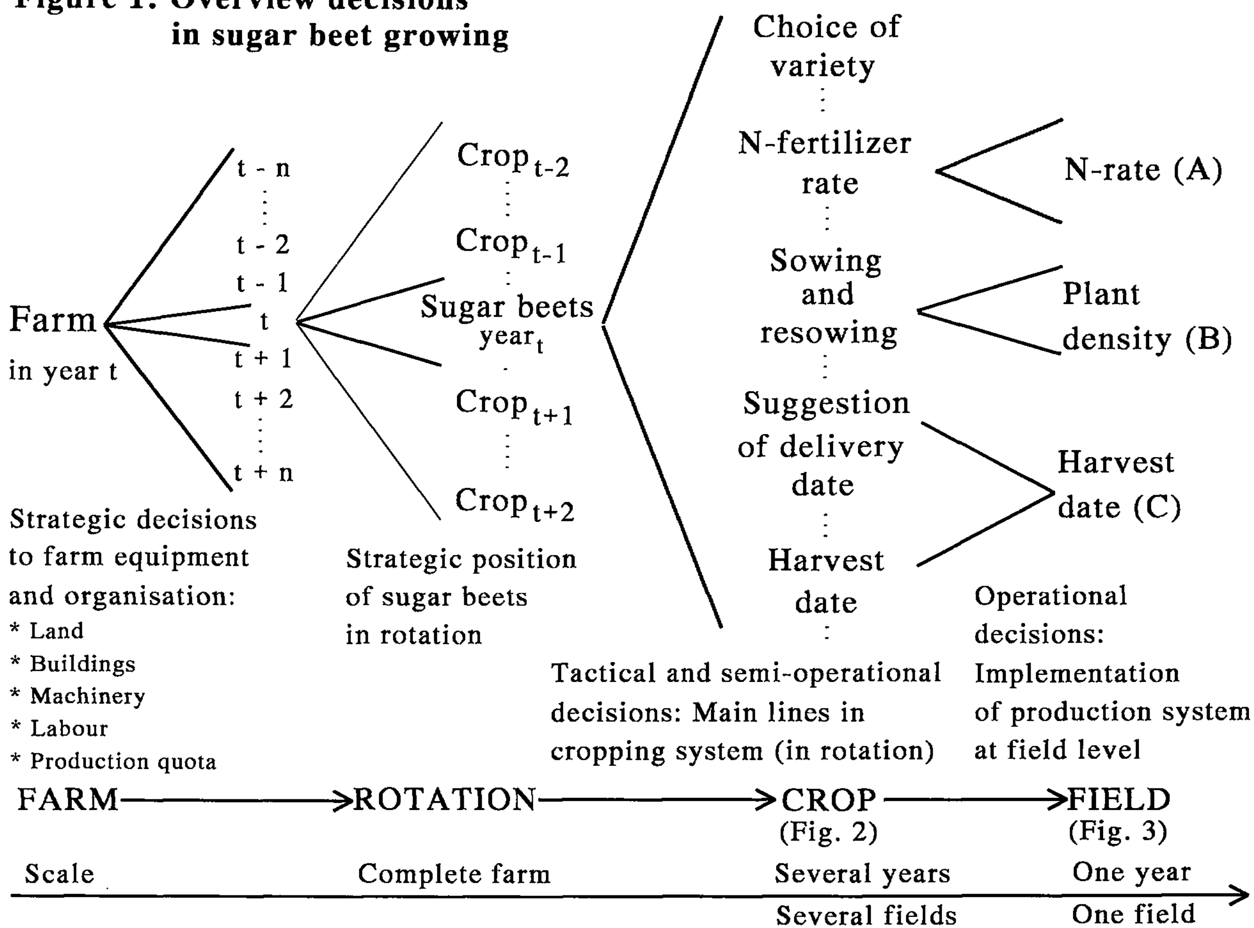
In general, three types of decision taking are discerned with decreasing time scale and economic effect and with increasing frequency: strategic, tactical and operational decisions (Alleblas, 1987; Van den Tempel and Giesen, 1992). In this chapter, decision making within the system of sugar beet production (at the aggregation levels cropping system (including crop rotation and production system) and crop) is described qualitatively. Section 2.2 describes the different types, applied on sugar beet growing, and Section 2.3 the different phases. The decisions at crop level are elaborated in Section 2.4. From all decisions described, some are given priority in the development of a basis for a decision support system for sugar beet growing; these are selected for further qualitative and quantitative analysis (Section 2.5 and other chapters in this thesis, respectively). The goals of the project and the structure of the thesis are described in Sections 2.6 and 2.7, respectively.

2.2 Decision making in sugar beet growing

Figure 1 describes the decisions to be taken in the farm system over time. From left to right, the level of aggregation decreases from farm, through crop rotations and cropping systems to crops in a certain field. Together with this, the type of decision changes from strategic to tactical and operational, and the period of time which is taken into account, decreases from several years to months or weeks.

Strategic decisions are least frequent and deal with the two left columns in Figure 1: 'farm' and 'rotation', or, in other words: farm size, farm equipment and long-term farm organisation. 'Farm size' deals with purchase or selling of land with or without a production quota for sugar beets; 'farm equipment' means construction of new buildings or replacement of old ones or, in the case of sugar beets, a concrete plateau for storage of the beets between harvest and delivery, and purchase or replacement of machinery, e.g. a chemical sprayer for row application; and 'long-term farm organisation' deals with crop rotation, percentage of the crops that is labour intensive, fixed labour force, etc. 'Crop

Figure 1: Overview decisions in sugar beet growing



rotation' is a more or less fixed pattern in the succession of crops on a certain field. It is determined by component crop species, the frequency of each component crop and the cropping sequence (Struik and Scholte, 1992). Crop rotation is partly determined by economic and hygienic reasons.

Tactical decisions are taken on matters with a time scale of about one growing season, e.g. the area and varieties of sugar beets in the next year, taking all relevant aspects of the crop rotation into account beforehand.

Operational decisions have to be taken during or just before the crop is grown. We call them 'semi-operational' when the decisions have to be taken only once, e.g. on sowing date. The third column of Figure 1 ('crop') gives both tactical and semi-operational decisions in sugar beet growing. The 'true' operational decisions (the fourth column in Figure 1, 'field') have commonly to be taken more than once during the season. Crop protection is the best example in this category, since decisions on (mainly) weed control have to be taken before and after emergence of sugar beets and in several growth phases of the crop until canopy closure. Regular observations are required to consider whether damage thresholds for one or more weed species are exceeded (Smit and Struik, 1995). Choices have to be made between hoeing, spraying or a combination of the two, in which weather forecasts and activities planned in other crops play a role. Risks that plans must be postponed or cancelled (as a result of unfavourable weather or soil conditions or crop status) must be taken into account as well.

The importance of optimal decision taking at field level has already been mentioned by Zachariasse (1974). Taking suboptimal decisions can greatly affect the technical and the farm economic results of the farm and, as a consequence, the income of the farmer.

2.3 The phases of decision making

Each type of decision can be considered as a cycle of three phases: identification, development and selection (Mintzberg *et al.*, 1976). The first phase, the identification phase, comprises two routines: problem recognition and diagnosis, in which the cause-effect relationships for the decision situation are determined. In the second phase, the development phase, one or more solutions to a problem are defined. In the search routine, ready-made solutions are sought for. These are modified in the design routine. In the case of sugar beet growing, the ready-made solutions, for example provided by extension services, are adapted for farm and field specific conditions, which is the central theme of this thesis. The third phase, the selection phase, comprises three sequential routines: screening, evaluation-choice and authorization. In the screening routine, the number of alternatives is reduced in a superficial way. In the evaluation-choice routine, from the remaining alternatives the best is selected. In the authorization phase, the decision maker induces action (Mintzberg *et al.*, 1976). After action, evaluation of the effects may result in a new cycle of decision making.

Before analysing the cycles of decision making for a number of specific problems selected, we describe the sequence of decisions in sugar beet growing at the cropping system level.

2.4 Sequence of decisions at cropping system level

Figure 2 shows a more detailed overview of the decisions at cropping system level, starting from the harvest of the crop preceding sugar beets and ending at the preparations for the crop following sugar beets. The figure contains tactical, semi-operational and operational decisions.

As to tactical aspects, the preceding crop has some influence on the performance of sugar beets, which has in turn an effect on the growth and production of the next crop. The area and varieties of sugar beet in the next season, which are decided on in December, are tactical and semi-operational decisions, respectively. Other (semi-)operational decisions deal for example with fertilizer application, weed and disease control, harvest and delivery dates. Fertilizer application and (preliminary) seedbed preparation take place in the early spring as soon as weather and soil conditions allow, and sowing after March 1st (in some mild regions in the South-western part of the country even in February). Until the end of June, when the crop canopy normally closes, weed control is the main activity. Disease control is mostly limited to yellowing disease (caused by Beet Yellow Virus (BYV) or Beet Mild Yellowing Virus (BMYV)). In some years, field emergence is low and/or irregular and decisions on resowing have to be taken about a month after sowing.

In the beginning of August, the sugar industry starts negotiations with the growers about their preferences on delivery dates. Within limitations, they can decide to deliver (part of) the beets relatively early or late. Later on, having received the final dates (or periods) in which the beets must be delivered, the grower must decide when which (parts of the) fields can be harvested best. This decision process is elaborated in Smit *et al.* (1994, 1996b). When there is a period of storage, the grower has to decide when and how to protect the clamp against potential frost damage.

The different decisions described are different for clay, loamy or loess soils, where manure application and major soil tillage take place in autumn, and sandy or reclaimed peat soils, where they take place in spring. Variation in soil properties, especially sensitivity to drought stress, preceding crop, size of the field, distance to the farm buildings and other

Figure 2: Sugar beet growing at crop level

State:	Time:		Action:
Preceding crop			
	Autumn		Harvest
Crop residues			
	Autumn/ Early spring		Manure application Soil tillage
Tilled field			
	December		Choice of variety Ordering of seed
	Early spring	A	Fertilizer application Seedbed preparation
Seedbed			
	March/April	B	Sowing Pre-emergence weed control
Emerging crop			
	April-June		Post-emergence weed control Crop protection
Closed canopy			
	Beginning of August		Suggestion of delivery date(s)
Crop residues Beet clamp	September- November	C	Harvest(s)
	September- November		Storage Delivery Preparations for following crop
Ploughed field			

characteristics within regions, farms and fields at a farm makes a field specific approach in decision making necessary.

2.5 Selection of decisions with priority

From Figure 2, three decisions were selected for further analysis: those on N-rate (A), plant density (B) [1] and harvest date (C). All three decisions have to be taken for every sugar beet field and greatly influence yield, quality, financial returns and impact on environment. Thus, they can be regarded as essential, basic decisions, the first ones in a whole list of decisions which could be studied after quantifying the (even greater) influences of weather and soil conditions. A, B and C are therefore the main decisions that are described and analysed in this thesis. Decision cycles and trees for the three decisions are given in Figures 3A-C. Zachariasse (1974) listed N-fertilization and plant density, among others, as factors with large effects on the root and sugar yields and sugar content of sugar beets.

Besides the three (semi-)operational decisions mentioned, decision taking on the area of beet to grow in the next season is described in this thesis (Smit *et al.*, 1996a); this decision cannot be easily described with a decision tree, since long-term calculations play an overruling role.

2.5.1 Nitrogen supply

The first step in deciding on nitrogen supply is the assessment of the optimal N-supply for a sugar beet field, based on soil analysis (which is common in Dutch arable farming) and rules of thumb of extension services (Figure 3A). The available amount of mineral N in the soil layer 0-60 cm is measured by soil analysis in February. The required N-rate is then calculated and applied. In the evaluation process, the colour and growth of the (mainly) young crop play an important role. In a wet spring, the colour of the crop around GPD may indicate a lack of nitrogen.

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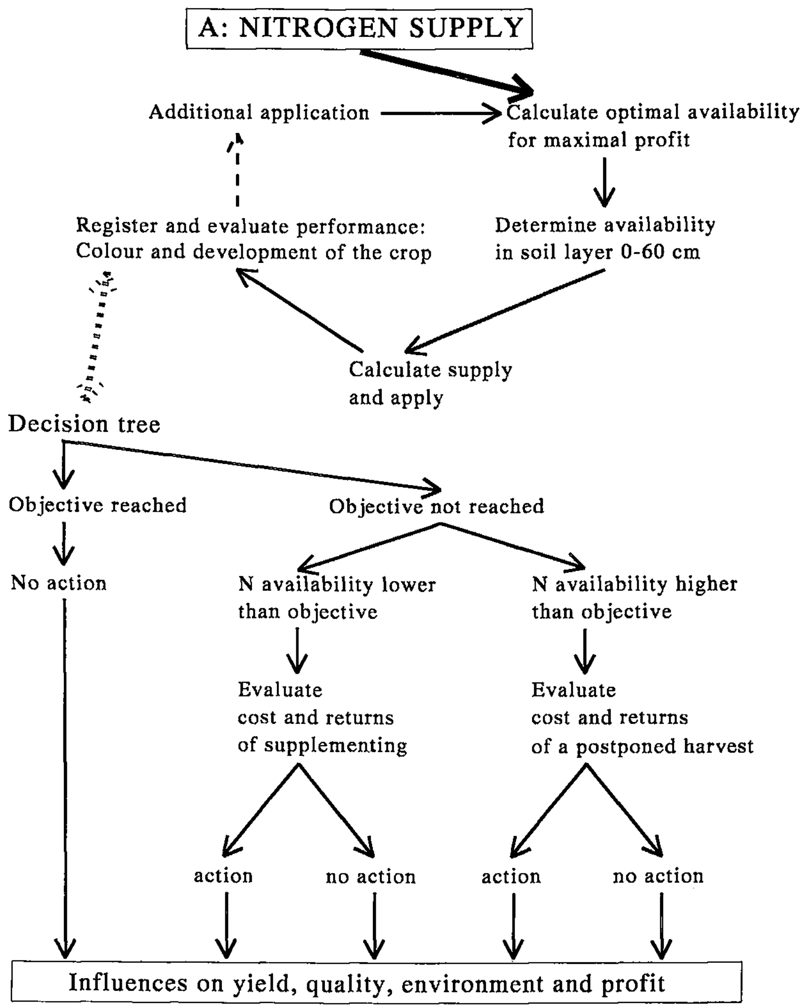
[1] In fact, plant density is not entirely determined by the grower's decision; it is partly the resultant of a combination of soil, weather and seed conditions and biological processes. The grower has some influence on these through careful soil tillage and seedbed preparation, selection of sowing distances and depths, chemical seed protection and sowing date, but after sowing there is not much he can do to establish a favourable plant density. In extreme situations, he can decide to resow, but the resulting plant density of the new crop is also greatly affected by conditions beyond his influence. However, the actual plant density will influence the crop structure and performance, and, as a consequence the expected yields and quality.

Figure 3: Selected decisions in sugar beet growing



The decision tree in Figure 3A shows that a favourable colour and a good performance of the crop lead to 'no action'. When the spring is wet, part of the applied nitrogen may be lost as a result of leaching or denitrification. As a consequence, the grower must consider supplementing. He will only apply additional N if an evaluation of expected costs and returns leads to a positive result.

It is also possible, that the available N turns to be higher than expected as a result of soil and weather conditions enhancing high N-mineralization rates and/or inducing poor internal quality. In that case, the grower may consider to harvest later than planned in order to minimize the decrease in quality. Higher amounts of nitrogen in post-harvest residues as a result of higher N-availability increase the probability of higher losses of N to the environment.

2.5.2 Plant density

From calculations on optimal density, a required plant distance [2] is derived, assuming an average field emergence (Figure 3B). Just before sowing, the original decision is refined, taking current soil and weather conditions into account. The performance of the emerging crop is evaluated through recording plant density and distribution in the 4-leaf stage or later.

When the plant density observed is considerably lower than the optimal one, the grower must consider resowing (Smit *et al.*, 1996c). When the plant density is higher than the optimal one, thinning may be a theoretical solution, but in practice the costs of such will largely exceed the returns.

2.5.3 Harvest date

Part of the decision process on harvest date in Figure 3C has already been described in 2.4. After the sugar industry has set delivery periods, the grower must decide on harvest dates and therefore estimate optimal harvest dates for the different (parts of the) fields. When time passes by, the grower will attentively study the weather forecasts and discuss his plans with contractors and assisting neighbour-farmers [3]. Considering all factors involved, the grower decides whether his plans should be changed or not. Risks of frost and heavy rainfall, the amount of C-sugar beets expected and timing of the harvest of ware or starch potatoes and of the sowing of following crops must be taken into account.

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[2] Assuming a fixed row distance of 50 cm.

[3] When cooperative transportation of beets from the field to the storage plateau takes place.

Figure 3: Selected decisions in sugar beet growing

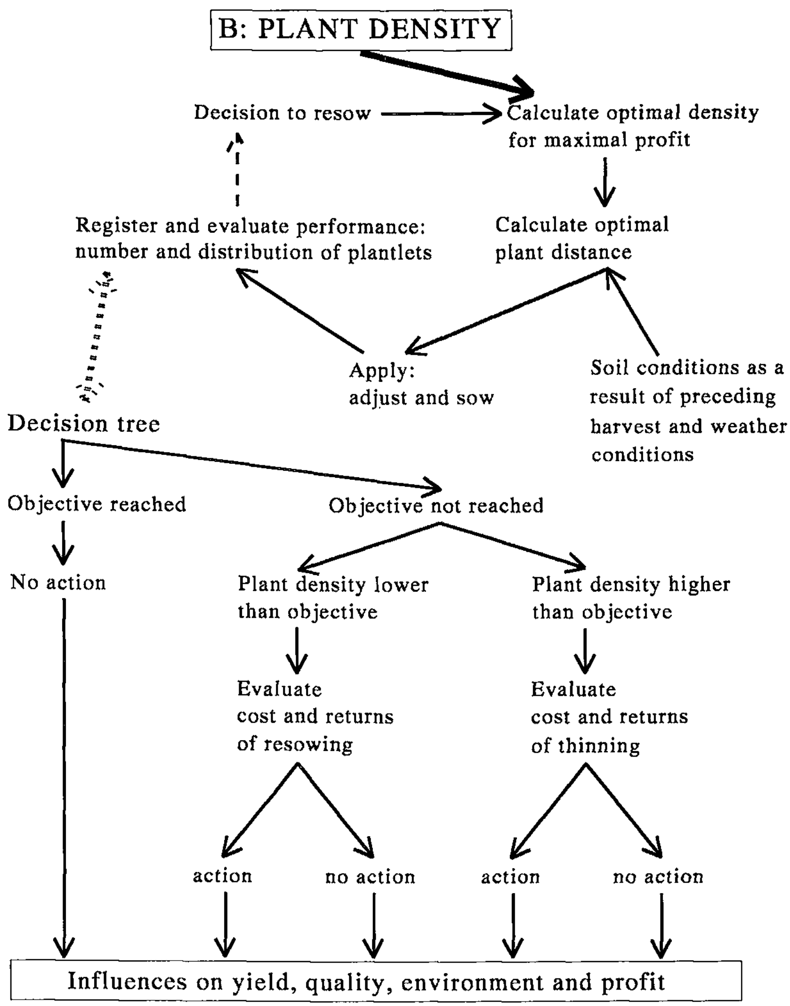
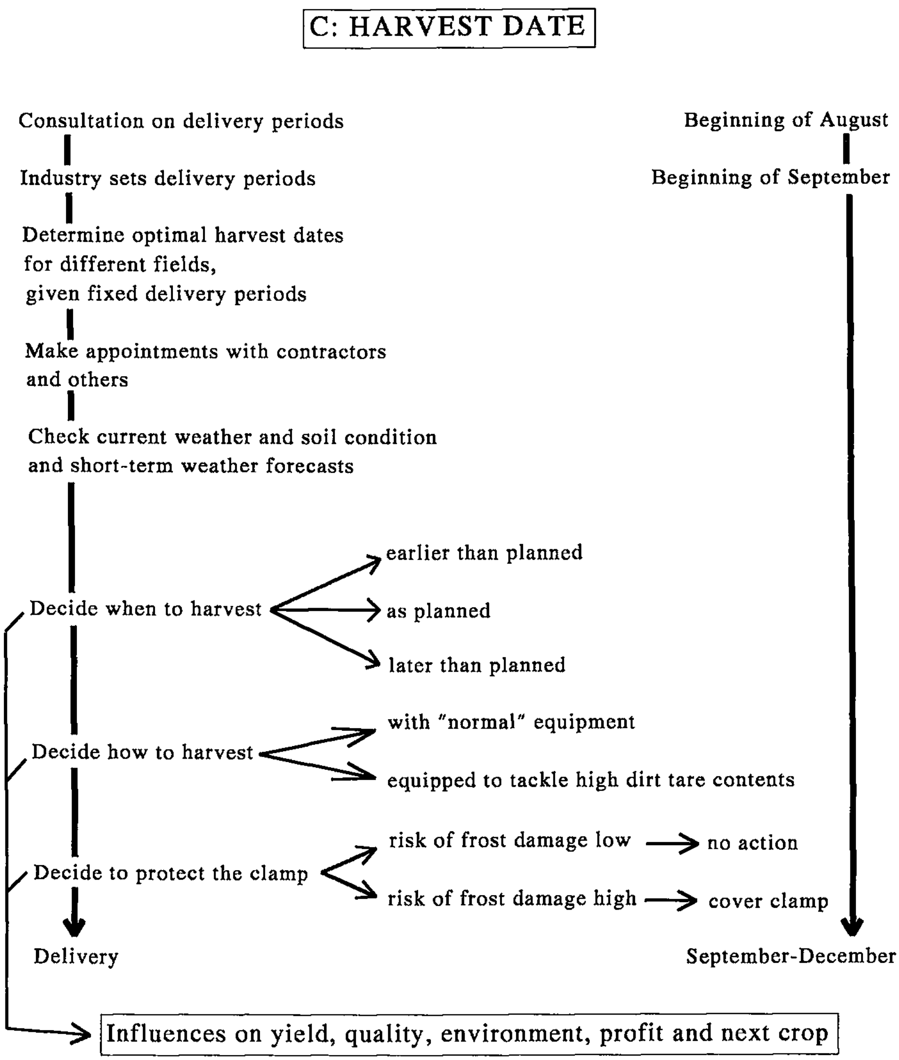


Figure 3: Selected decisions in sugar beet growing



Under poor weather and soil conditions, the harvest and transportation machinery may be equipped with special tires and cleaning tools (e.g. brushes) to keep soil structure damage and dirt tares relatively low. These adaptations may lead to higher costs and harvest losses, which have to be taken into account as well.

In considering clamp protection, weather forecasts play an important role. Costs of labour and materials will make the grower reluctant to cover the clamp(s), especially when only one or two cold nights are expected. When longer periods of low temperatures are expected, frost damage to the beets becomes an increasingly important risk.

For all decisions on harvest date, long term costs and returns play a role besides the short term calculations. Heavy soil structure damage may lead to yield reduction and other problems in the next crop, which should be considered as costs of the sugar beet crop.

2.6 Goals of the project

So far, the system description has been qualitative; for decision support of sugar beet growers, field specific knowledge about the quantitative relationships between input and output variables under different weather and soil conditions is required. Therefore, the effects of decisions on N-fertilization, plant density and harvest date, and their possible interactions must be quantified in a reliable and realistic way. The project summarized in this thesis, was designed to answer the questions raised.

The main goals of the project 'The development of a field specific bio-economic production model for sugar beet growing' were:

1 to develop a growth model for sugar beet as required for decision support;
2 to analyse and quantify the effects of different levels of nitrogen availability, plant density and harvest date on yield, quality, financial returns and environmental aspects;
3 to develop ideas how the relationships derived could be integrated into a decision support system for sugar beet growing in general and specifically at field level.

In the next chapters we present the methods and materials, and the results of the different steps in the modelling process. In every step, attention is paid not only to calibration of the model but also to validation and evaluation.

2.7 Structure of the thesis

The thesis contains 11 chapters, including the previous chapter and this chapter. After the introductory Chapters 1 and 2, a basic model is selected in Chapter 3. The structure and performance of this model, PIEteR, including a number of improvements, are the subjects of Chapter 4. In Chapter 5, attention is paid to the sugar, (K + Na) and α-amino-N contents, the extractability index and the operating receipts, which were not included in the prototype version of PIEteR. Besides, the modelling of the effects of plant density on yield and quality parameters is described. Chapter 6 gives insight into decisions on resowing, in which plant density plays a major role. Chapter 7 deals with the effects of nitrogen availability on yield and quality parameters, operating receipts and also on the amounts of residual N in crop residues. In Chapter 8, dirt and crown tare contents are added to the list of parameters simulated. The effects of harvest date on the different parameters and the risks involved in harvest postponement are also part of this chapter. Chapter 9 gives an overall evaluation and validation of the model and shows how the different modules can be integrated for decision support. In Chapter 10, tactical decisions on the area of sugar beets are studied. Chapter 11 contains the final general discussion.

References

Alleblas, J.T.W., 1987. Management in de glastuinbouw; een zaak van passen en meten. Den Haag, LEI-DLO, Onderzoeksverslag 34, 217 pp.

Mintzberg, H., D. Raisinghani & A. Théorêt, 1976. The structure of "unstructured" decision processes. *Administrative Science Quarterly* **21**, 246-274.

Smit, A.B., J.H. van Niejenhuis & P.C. Struik, 1994. Introduction to a bio-economic production model for sugar beet growing. In: Struik, P.C., W.J. Vredenberg, J.A. Renkema and J.E. Parlevliet (eds.). Plant production on the threshold of a new century. Proceedings of the International Conference at the occasion of the 75th Anniversary of the Wageningen Agricultural University, Wageningen, The Netherlands, held June 28 - July 1, 1993. Developments in plant and soil sciences, 61. Dordrecht/Boston/London, Kluwer Academic Publishers: 115-122.

Smit, A.B. & P.C. Struik, 1995. PIEteR: a field-specific production model for sugar beet growing. *Journal of Agronomy and Crop Science* **175**, 335-348.

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1995. Modelling the influence of plant density on yield, sugar content and extractability of sugar beet. In: Proceedings of the 58th IIRB-congress, 19-22 June 1995, France. IIRB, Brussels, 413-424.

Smit, A.B., J.H. van Niejenhuis & J.A. Renkema, 1996a. A farm economic module for tactical decisions on sugar beet area. *Netherlands Journal of Agricultural Science* (submitted).

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1996b. Prediction of various effects of harvest date in sugar beet growing. *Journal of Agricultural Engineering Research* (submitted).

Smit, A.B., P.C. Struik, J.H. van Niejenhuis & J.A. Renkema, 1996c. Critical plant densities for resowing. *Journal of Agronomy and Crop Science* (in press).

Struik, P.C. & K. Scholte, 1992. Crop rotation. In: Meulenbroek J.L. (ed.). Proceedings Congress Agriculture & Environment in Eastern Europe and The Netherlands. Wageningen, The Netherlands, WAU: 395-407.

Tempel, van den, F.C.A. & G.W.J. Giesen, 1992. Agrarische bedrijfseconomie. Inleiding. Culemborg, Educaboek, 455 pp.

Zachariasse, L.C., 1974. Boer en bedrijfsresultaat. Analyse van de uiteenlopende rentabiliteit van vergelijkbare akkerbouwbedrijven in de Noord-Oost-Polder. Wageningen, WAU. PhD-thesis, 122 pp.

CHAPTER 3

The first step towards a decision support system for sugar beet growing: selection of a basic growth model

A.B. Smit & P.C. Struik

Abstract

Four simulation models were tested for their suitability as a basic growth model in a decision support system for sugar beet growing in The Netherlands. SUCROS and SUBEMO are complex, mechanistic models; LINTUL and PIEteR are relatively simple regression models including causal relationships at a higher level of integration. All four models are dynamic, i.e. they calculate daily growth and production rates.

The selected model had to be able to predict root and sugar yields accurately and to correct for suboptimal water contents of the soil. It should be possible to include location-specific data and new modules, e.g. for nitrogen fertilization or plant density. Finally, the farmer should be able to collect the required input data easily and cheaply.

The tests showed that PIEteR predicted root and sugar yields best, partly because it contained water balance corrections, based on location-specific soil characteristics. PIEteR could not be applied universally because of its regression character at a high level of integration, but it met the requirements specified.

Keywords: sugar beet, *Beta vulgaris*, decision support, simulation model

Introduction

A multi-disciplinary research project is in progress (Smit *et al.*, 1994) to construct a decision support system for sugar beet (*Beta vulgaris* L.) growing, based on bio-economic models. These models must be able to predict yield, quality, financial returns and post-harvest nitrogen residues at field level under Dutch conditions.

Various crop growth models are compared, to find the one most suitable to serve as a basis for this type of decision support. The selected model has to meet the following criteria:

- be able to predict final root and sugar yields accurately;
- allow easy incorporation of location-specific data and new modules, e.g. for nitrogen

fertilization or plant density;
- be able to predict yields accurately throughout the season under conditions of 'normal' practice;
- generate predictions that are field-specific and take year-to-year variations into account;
- require input data that the farmer can collect simply and cheaply (Biemond, 1989).

This paper briefly describes each of the four models evaluated and the results of testing them with 20 data sets.

Materials and methods

1. Description of models

The four models available for the test were: a simple version of LINTUL (Smit, 1990); SUBEMO (Vandendriessche, 1989a,b); SUCROS for sugar beet, in different versions with and without water balance corrections (Spitters, 1989); and PIEteR (Biemond *et al.*, 1989; Greve, 1992).

1.1 LINTUL

LINTUL (Light **INT**erception and **U**ti**L**ization simulator) is a dynamic regression model (Spitters, 1989, 1990). A.L. Smit's version of LINTUL for sugar beet calculates a daily increase of the leaf area index (LAI) from emergence onwards; this increase is assumed to be linearly related to temperature, within defined limits. Sugar production starts at canopy closure; it is expressed as a function of intercepted radiation, which in turn is a function of LAI and total radiation. In the model, the conversion factor from intercepted radiation to sugar production is constant during the entire growing season.

LINTUL was originally developed for the newly reclaimed regions 'Flevoland' and 'Noordoostpolder'. In these regions the efficiency of sugar production is higher than elsewhere in The Netherlands, because of their very favourable growing conditions (Smit, 1990). To enable the model to be applied to other regions it was adjusted in accordance with Spitters *et al.* (1990).

The input LINTUL requires includes sowing and harvest dates, daily values for average temperature and total radiation.

1.2 SUBEMO

SUBEMO (**SU**gar **BE**et **MO**del) is a more complex, mechanistic model, calculating the sugar content and dry matter and sugar production per hour (Vandendriessche, 1989a,b). Physiological processes are simulated at organ level. The assimilation rate is determined by the most limiting of the following factors: temperature, total radiation and relative plant water content. The partitioning ratios for respiration, growth of leaves, fibrous roots and beet roots, and sugar accumulation are calculated per hour. Recovery of dry matter from senescent leaves is also taken into account.

The model requires many input data in addition to daily weather data and site characteristics. The crop information required to initialize the model has to be estimated or collected by sampling the crop. The model does not predict emergence date.

1.3 SUCROS

The third model, SUCROS (a Simple and Universal CROp growth Simulator), has been described by Van Keulen *et al.* (1982). It is a complex, mechanistic model which simulates the dry matter production of a crop from emergence until maturity as a function of daily total radiation and air temperature. Partitioning functions play an important role. The subsequent partitioning coefficients for roots, leaves, stems and storage organs are introduced as functions of the phenological state of the crop, but are not calculated hourly.

The version for sugar beet was based on SUCROS87, the 1987 version of SUCROS, and has been described by Spitters *et al.* (1989). In the prototype version (SUCROS1) water or plant nutrients were assumed not to be limiting. In our evaluation we used updated parameters (see: Kropff *et al.*, 1993). In 1993, W. Stol and A.B. Smit developed a version of SUCROS with a soil water balance (SUCROS2, unpublished), based on similar work for spring wheat by Van Keulen *et al.* (1992). We tested both versions of SUCROS. We derived fresh root yield at final harvest from dry root yield by assuming a dry matter content of 24%. All versions of SUCROS require sowing date, harvest date, and daily weather data as input.

After a first run we decided to combine both versions into 'SUCROS12' which calculated the soil water balance for every region, except for the regions 'Flevoland' and 'Noordoostpolder'; SUCROS2 strongly overestimated the effect of drought on production in these regions.

1.4 PIEteR

The fourth model, PIEteR (Production model for sugar beet, including Interactions between Environment and growing decisions, and their influence on the quantitative, qualitative and financial Result), is a regression model based on the assumption that after GPD [1] sugar production can be predicted by a linear relationship between intercepted radiation and sugar production (Biemond, 1989). PIEteR predicts emergence date, GPD and daily root and sugar production. Its light use efficiency functions are based on a direct relationship between daily

[1] GPD is the 'Growth Point Date', which nearly coincides with the day on which the canopy closes, i.e. leaves from adjacent rows touch. Details are given in Smit and Struik (1995).

total radiation and daily (fresh) root and sugar production.

The yield-determining factors were easily identified and incorporated in prototype versions of PIEteR. However, in earlier phases of this project it had already been found that inadequate water supply (mainly drought stress) was the main yield-limiting factor in sugar beet growing (Biemond, 1989; Biemond, *et al.* 1989). In The Netherlands 25% of the sugar beet crop is grown on (mostly sandy) soils which are susceptible to water stress (Van der Beek and Houtman, 1993). Therefore, to be able to make accurate predictions at field level a module to take water stress into account is required.

PIEteR calculates a daily soil water balance. In non-optimal situations (too dry or too wet), the calculated daily growth and production rates are adjusted. The model calculates daily average temperatures from data on minimum and maximum temperatures according to Van Kraalingen and Rappoldt (Goudriaan and Van Laar, 1994). In addition to weather data, PIEteR requires sowing and harvest dates and soil characteristics (*lutum* [2] and organic matter content).

To recap: all the models tested are dynamic, but they differ in their level of detail. They simulate growth and, after a certain transition point, hourly or daily production. SUBEMO and SUCROS are explanatory models. LINTUL and PIEteR can be classified as descriptive regression models, in which causal relationships at a higher level of integration are included.

2. *Input and output of the test*

The four models were tested on 20 data sets from experimental fields (Table 1). The weather input was not always ideal; in some cases data from a more distant weather station had to be used because insufficient computerised data were available from the local station. This may have influenced the reliability of rainfall data, because rainfall often varies greatly over short distances (A.F.G. Jacobs, WAU, Department of Meteorology, pers. comm., 1992). Part of the required input for SUBEMO had to be estimated (mainly the number of leaves initially present and their respective ages).

LINTUL simulated sugar yield only, but fresh root yield was calculated by assuming a fixed sugar content of 75% on a dry matter basis and a fixed dry matter content of 24% at final harvest. The output of SUBEMO consisted of dry matter and sugar yields, and dry matter and sugar contents. Fresh root yield can be calculated from these parameters. Both SUCROS and PIEteR simulated fresh root and sugar yields.

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[2] *Lutum* is defined as the fraction of the soil texture with particles smaller than 2 μm (clay).

Table 1. The data sets used to test the models

No.	R [1]	Contents in soil: Organic matter (%)	Contents in soil: Lutum (%) [2]	Sowing date [3]	Harvest date [3]	Plant density (m^{-2})	Fresh root ($kg.m^{-2}$)	Sugar content (%)
1	1	1.2	26	85	277	4.06	5.39	16.06
2	2	1.9	38	105	315	6.38	6.24	17.14
3	8	8.0	0	95	291	7.02	5.55	16.90
4	2	1.3	18	105	297	6.87	7.76	16.81
5	2	1.5	22	106	304	5.93	5.60	17.28
6	7	5.5	0	103	303	8.52	5.54	17.14
7	8	7.6	0	93	272	8.86	5.85	15.67
8	2	1.7	34	107	266	7.89	5.85	16.20
9	1	1.5	24	101	282	8.86	5.63	18.09
10	5	2.1	23	97	266	7.83	6.71	16.90.
11	2	1.9	24	96	329	8.29	7.42	17.14
12	2	1.6	20	104	297	8.13	6.54	15.85
13	1	1.6	39	95	299	8.72	6.24	17.21
14	4	3.4	40	90	305	5.97	8.64	16.13
15	8	7.6	0	92	277	9.23	5.45	17.48
16	5	1.9	23	91	293	8.21	7.79	17.47
17	4	2.2	24	108	312	10.29	7.42	17.97
18	4	2.2	24	97	315	9.12	8.31	16.93
19	4	2.2	24	93	307	7.60	7.80	18.81
20	4	2.2	24	152	313	6.80	6.07	17.53

[1] The code refers to one of the 11 regions discerned by the Dutch Sugar Beet Research Institute at Bergen op Zoom (IRS):

1 Zeeland (clay soils)
2 West-Brabant and Zuid-Holland islands (clay soils)
4 Zuidoost-Flevoland (newly reclaimed clay soils)
5 Noordoost-Polder (newly reclaimed, predominantly clay soils)
7 Sandy regions in the Northern part of The Netherlands
8 Veenkoloniën (reclaimed peat soils).

[2] The fraction of the soil texture with particles smaller than 2 μm (clay).

[3] Expressed as day of year. The data were obtained in 1978 or in 1980, 1981, 1982 or 1983.

3. Method of comparison of model performance

The model predictions of root and sugar yields were compared with the experimental results. To assess the accuracy of the models the prediction errors, i.e. the absolute differences between experimental and simulated yields, both in kg.m^{-2} and as percentage of the experimental yield, were calculated and averaged over the 20 fields. The coefficient of determination, R^2, was calculated as an indicator of the ability to predict yield with accuracy under various circumstances. R^2 is the proportion of variation in a variable Y about the mean that can be accounted for by fitting Y into a particular model instead of viewing the variable in isolation (Anderson-Sprecher, 1994).

The simulation results and the prediction errors were tested for systematic over- or underprediction and for trend as a function of observed yields respectively, using the F-test, Wilcoxon's signed rank test and Spearman's rank correlation test (Rossing, 1993; Snedecor and Cochran, 1980). In the F-test, the null hypothesis is that the prediction error is zero. The alternative hypothesis allows for bias in the expected prediction error which is a linear function of observed yield. Spearman's test evaluates whether there is a trend in the prediction error. The null hypothesis is that there is no rank correlation between the prediction error and the observed yield. Wilcoxon's test detects systematic over- or underprediction. The null hypothesis is that the predicted and the observed yields are distributed similarly.

Results

Tables 2-4 and Figures 1A-B show the main results of the tests. On average, LINTUL, SUCROS1 and PIEteR overpredicted both root and sugar production. SUBEMO and SUCROS2 underpredicted both variables and SUCROS12 underpredicted root production and overpredicted sugar production. The mean prediction errors between the observed and simulated yields varied between 16% for LINTUL and SUCROS12, and 26% for SUCROS1 for root yield, and between 13% for PIEteR and 41% for SUBEMO for sugar yield. All models explained 40% or less of the variance in the observed root and sugar yields, except for PIEteR, which explained 67% and 79%, respectively.

From Spearman's test we concluded rank correlation between prediction error and observed yield for all models except PIEteR for both root and sugar yields. The results of Wilcoxon's signed rank test indicated that the overprediction of LINTUL and SUCROS1, and the underprediction of SUBEMO were significant for both root and sugar yields. PIEteR overpredicted only root yield significantly. The combining F-test showed that all models except PIEteR had a systematic over- or underprediction and/or a trend in the expected prediction error. On average, the predictions of PIEteR were too high, but the errors seemed to be constant and independent of yield level observed.

Table 2. Observed and simulated (fresh) root and sugar yields of six models or model versions. Means of 20 experimental fields in different years and regions.

Experiment/model	Fresh root yield ($kg.m^{-2}$)	Sugar yield ($kg.m^{-2}$)
Experimental value	6.50	1.12
Simulated value:		
LINTUL	7.15	1.29
SUBEMO	4.99	0.65
SUCROS1	7.87	1.42
SUCROS2	5.53	1.00
SUCROS12	6.27	1.22
PIEteR	7.57	1.25

Table 3. Mean prediction errors and the respective explained variances of six models or model versions. Means of 20 experimental fields in different years and regions.

Model	Fresh root yield			Sugar yield		
	Mean prediction error		Explained variance	Mean prediction error		Explained variance
	($kg.m^{-2}$)	(%)	(%)	($kg.m^{-2}$)	(%)	(%)
LINTUL	0.98	16.1	16.4	0.20	19.5	17.3
SUBEMO	1.52	22.1	12.0	0.47	40.6	12.8
SUCROS1	1.37	22.9	22.3	0.30	28.8	20.2
SUCROS2	1.75	26.0	10.3	0.34	29.4	16.2
SUCROS12	1.02	16.1	11.0	0.19	18.5	38.3
PIEteR	1.11	17.4	67.1	0.14	12.9	79.4

Discussion

We chose LINTUL as a reference model for the comparison, because it showed the performance of a relatively simple model; it would only be useful to choose a more complex model to predict yield if it performed better than LINTUL.

Of all models and versions of models tested, only SUCROS12 and PIEteR had equal or smaller prediction errors than LINTUL for both root and sugar yields, and only SUCROS1 and PIEteR had higher R^2 values for both variables (Tables 1 and 2). The predictions of PIEteR were the most accurate and precise. The three tests supported this conclusion.

Table 4. Statistical evaluation of six models or model versions. Means of 20 experimental fields in different years and regions. The variables f, d^2 and S_A represent the statistics of the F-test [1], Spearman's rank correlation test [2] and Wilcoxon's signed rank test [3], respectively (n=20).

Model	Fresh root yield			Sugar yield		
	f	d^2	S_A	f	d^2	S_A
LINTUL	143.1 **	2372 **	492 *	153.7 **	2384 **	503 *
SUBEMO	240.1 **	2466 **	227 **	478.3 **	2510 **	210 **
SUCROS1	62.8 **	2240 **	549 **	80.5 **	2268 **	566 **
SUCROS2	34.7 **	2190 **	352	21.9 **	2388 **	363
SUCROS12	62.2 **	2126 **	414	3.7 *	1986 *	470
PIEteR	1.7	1498	514 **	2.3	1512	482

* $p < 0.05$
** $p < 0.01$

[1] F-test: the null hypothesis is rejected when f is greater than 3.55 (p = 0.05) or greater than 6.01 (p = 0.01).

[2] Spearman: the null hypothesis is rejected when d^2 is outside the range [828, 1832] (p = 0.05) or [620, 2040] (p = 0.01).

[3] Wilcoxon: the null hypothesis is rejected when S_A is outside the range [337, 483] (p = 0.05) or [315, 505] (p = 0.01).

The most detailed model, SUBEMO, produced less accurate predictions than LINTUL, the simplest model. In general, mechanistic models are developed to elucidate fundamental plant processes. Because of their low level of integration, these models usually have many estimated parameters, each with an associated error. Hence, the final yield predictions, the combination of all detailed processes and their respective errors, may be very inaccurate (Spitters, 1989). There are plans to improve SUBEMO in the near future (H. Vandendriessche, Institute for Soil Research, Leuven-Heverlee, Belgium, pers. comm., 1994).

SUCROS is also mechanistic but is less detailed than SUBEMO. Its predictions were more accurate. When a water balance module was included in SUCROS, the predictions improved for most regions. The water balance in SUCROS is based on the assumption of a soil profile without capillary water transport. This leads to an underestimation of water availability in the

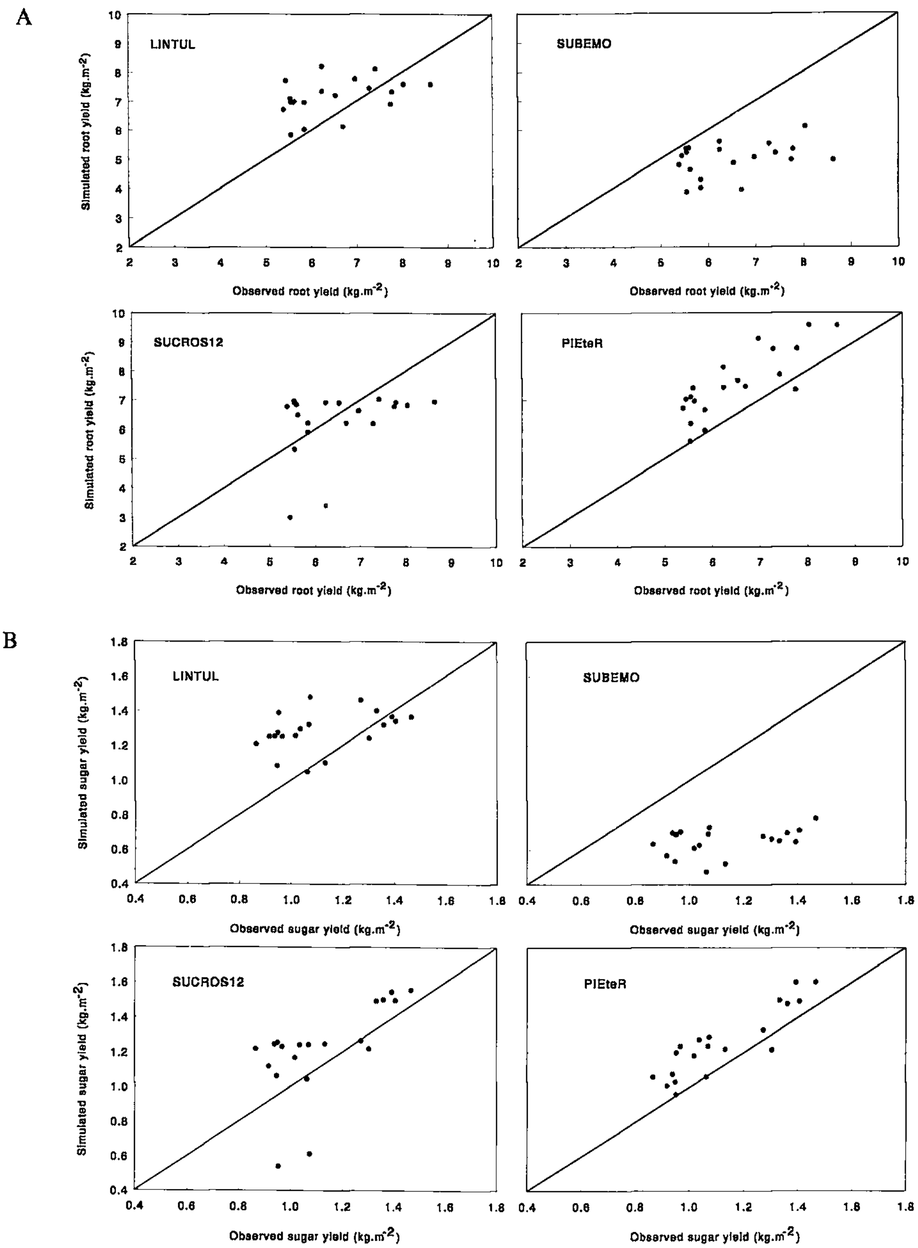

Figure 1. Simulated versus observed yield, plotted for four models, LINTUL, SUBEMO, SUCROS12 and PIEteR. A: fresh root yield; B: sugar yield (__: line Y = X).

Lake IJssel polders, where this type of transport is important (W. Stol, Institute for Agrobiological and Fertility Research (AB-DLO), Wageningen, pers. comm., 1993). Even under dry conditions, the observed yields in the polders equalled the predictions of SUCROS1, which approximated non-limited production. The root and sugar yields of two fields outside the Lake IJssel polders were severely underestimated (Figures 1A-B). The growing season in question (1982 in both cases) was relatively dry, warm and sunny. The sum of daily total radiation during the months April-October was higher than the average value for 1980 and 1981 (3.0 vs. 2.8 $GJ.m^{-2}$). The total precipitation was lower (361 vs 522 mm) and the average minimum and maximum temperatures were higher (9.5 vs. 8.7 °C, and 19.1 vs. 17.6 °C, respectively). The water balance module brought about a strong reduction of simulated growth. On the other hand, the root and sugar yield predictions of SUCROS1 for these two fields were much higher (more than 8.4 and 1.5 $kg.m^{-2}$, respectively), suggesting that capillary water transport had a remarkable effect on the respective yields, but not as much as in the Lake IJssel polders.

The water balance in PIEteR has a different character than the one in SUCROS. In PIEteR, it is assumed that capillary transport of water is possible over a soil layer of 2 m. Compared with SUCROS12, PIEteR could cope better with extreme situations (Figure 1A). Note that the differences between the sugar yield predictions of SUCROS12 and PIEteR were much smaller than those between the root yield predictions. This may partial due to the use of a constant dry matter content of 24% in SUCROS.

The input of PIEteR consists partly of location-specific soil data, i.e. *lutum* and organic matter contents, which are recorded in the farmer's soil reports. The remainder of the input data can easily be acquired at low cost. Data on total radiation and minimum and maximum temperatures are published daily for different regions. The farmer can record rainfall, which is more location-specific than the other weather data, with a simple instrument and may decide to record minimum and maximum temperatures as well.

Thanks to the overall character of relationships in PIEteR it is relatively simple to incorporate new modules, e.g. for nitrogen nutrition and plant density, in that model. Doing so in mechanistic models would require quantitative information on the influence of such factors on the various fundamental processes. On the other hand, the regression character of PIEteR restricts its application to the regions which were included when calibrating the model.

From our evaluation we concluded that PIEteR would best meet the requirements for our decision support system under Dutch circumstances.

Zusammenfassung

Ein erster Schritt zu einem Entscheidung unterstützenden System im Anbau von Zuckerrüben: Auswahl eines grundlegenden Wachstumsmodells

Vier Simulationsmodelle wurden hinsichtlich ihrer Eignung als grundlegende Wachstumsmodelle für Zuckerrübenanbau in den Niederlanden untersucht. SUCROS und SUBEMO sind komplexe, mechanistische Modelle; LINTUL und PIEteR sind vergleichsweise einfache Regressionsmodelle einschließlich kausaler Beziehungen auf einer höheren Integrationsebene. Alle vier Modelle sind dynamisch, d.h. sie berechnen tägliche Entwicklungs- und Produktionsraten.

Das auszuwählende Modell sollte in der Lage sein, Wurzel- und Zuckererträge genau vorauszusagen und für suboptimale Bodenwassergehalte zu korrigieren. Es sollte ferner möglich sein, ortsspezifische Daten und neue Einflußgrößen, z.B. für Stickstoffdüngung oder Bestandesdichte aufzunehmen. Schließlich sollte der Anbauer in der Lage sein, die benötigten Daten leicht und preiswert zu bestimmen.

Die Modellvoraussagen wurden für 20 Zuckerrübenbestände statistisch mit einem F-Test, dem Spearman's Rangkorrelationstest und dem Wilcoxon's 'signed' Rangtest ausgewertet. Die Tests ergaben, daß PIEteR Wurzel- und Zuckererträge am besten voraussagte; dies dürfte z. Teil darauf beruhen, daß dieser Test auf der Grundlage ortsspezifischer Bodeneigenschaften einen Wasserausgleich berücksichtigt. PIEteR konnte auf Grund seiner Regressionseigenschaft mit hoher Integrationsebene nicht universell angewendet werden; das Modell genügte aber den spezifizierten Anforderungen.

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References

Anderson-Sprecher, R., 1994. Model comparisons and R^2. The American Statistician **48**, 2, 113-117.

Beek, van der, M.A. & H.J. Houtman, 1993. Does interaction between varieties and drought stress exist? In: Proceedings IIRB-Congress, Brussels, 10-11 February 1993. Brussels, IIRB: 151-169.

Biemond, T., 1989. Nota: "Ontwikkeling van nauwkeurig suikerbieten produktiemodel". In: Biemond, T. (ed.). Produktiemodel suikerbieten. Rapportage workshop 3 mei 1989. Wageningen, WAU, Department of Farm Economics: 23-24.

Biemond, T., H.J. Greve, T. Schiphouwer & A.J. Verhage, 1989. Pieter, semi green-box produktiemodel suikerbieten. Wageningen, WAU, Department of Farm Economics, 31 pp.

Goudriaan, J. & H.H. van Laar, 1994. Modelling potential crop growth processes. Dordrecht, Kluwer, 238 pp.

Greve, H.J., 1992. Rapport perceelsgericht produktiemodel. Breda, Suiker Unie, 14 pp. (plus appendices).

Keulen, van, H., F.W.T. Penning de Vries & E.M. Drees, 1982. A summary model for crop growth. In: F.W.T. Penning de Vries and H.H. van Laar (eds.). Simulation of plant growth and crop production. Simulation Monographs. Wageningen, Pudoc: 87-97.

Keulen, van, H., J. Goudriaan, L. Stroosnijder, E.A. Lantinga & H.H. van Laar, 1992. Crop growth model for water-limited production (SUCROS2). In: H.H. van Laar, J. Goudriaan and H. van Keulen (eds.). Simulation of crop growth for potential and water-limited production situations (as applied to wheat). Wageningen, DLO/WAU, Simulation Reports CABO-TT, 78 pp.

Kropff, M.J., S.E. Weaver, L.A.P. Lotz, J.L. Lindquist, W. Joenje, B.J. Schnieders, N.C. van Keulen, T.R. Migo & F.F. Fajardo, 1993. Understanding crop-weed interactions in field situations. In: M.J. Kropff and H.H. van Laar (eds). Modelling crop-weed interactions. Wallingford, CAB International: 113-124, 245.

Rossing, W.A.H., 1993. On damage, uncertainty and risk in supervised control of aphids and brown rust in winter wheat as an example. Wageningen, WAU, PhD-thesis, 202 pp.

Smit, A.L., 1990. Teeltvervroeging bij suikerbieten. Een verslag van uitgevoerde proeven op het PAGV in de periode 1985 t/m 1988 in het kader van project 56.4.14. Lelystad, The Netherlands, PAGV-verslag 100, 52 pp.

Smit, A.B., J.H. van Niejenhuis & P.C. Struik, 1994. Introduction to a bio-economic production model for sugar beet growing. In: P.C. Struik, W.J. Vredenberg, J.A. Renkema and J.E. Parlevliet (eds.). Plant production on the threshold of a new century. Proceedings of the International Conference at the occasion of the 75th Anniversary of the Wageningen Agricultural University, Wageningen, The Netherlands, held June 28 - July 1, 1993. Developments in plant and soil sciences, 61. Dordrecht, Kluwer: 115-122.

Smit, A.B. & P.C. Struik, 1995. PIEteR: a field-specific production model for sugar beet growing. *Journal of Agronomy and Crop Science* **175**, 335-348.

Snedecor, N.J. & W.G. Cochran, 1980. Statistical methods. Iowa State University Press, 7th edition. 507 pp.

Spitters, C.T.J., 1989. Een regressiemodel en een mechanistisch model voor de voorspelling van suikerbietenopbrengsten. In: Biemond, T. (ed.). Produktiemodel suikerbieten. Rapportage workshop 3 mei 1989. Wageningen, WAU, Department of Farm Economics: 7-8, 47-48.

Spitters, C.J.T., 1990. Crop growth models: their usefulness and limitations. *Acta Horticulturae* **267**, 349-368.

Spitters, C.J.T., H. van Keulen & D.W.G. van Kraalingen, 1989. A simple and universal crop growth simulator: SUCROS87. In: R. Rabbinge, S.A. Ward & H.H. van Laar (eds.). Simulation and systems management in crop protection. Wageningen, Pudoc, Simulation Monographs, 32: 147-181.

Spitters, C.J.T., B. Kiewiet & T. Schiphouwer, 1990. A weather-based yield-forecasting model for sugar beet. *Netherlands Journal of Agricultural Science* **38**, 731-735.

Vandendriessche, H., 1989a. Het suikerbietenmodel SUBEMO (Sugar Beet Model). In: Comité voor Toegepaste Bodemkunde (ed.). Simulatie als hulpmiddel bij het stikstofbemestingsadvies voor de teelten wintertarwe en suikerbieten. Brussels, IWONL: 83-90, 216-223.

Vandendriessche, H., 1989b. SUBEMO-model. In: Biemond, T. (ed). Produktiemodel suikerbieten. Rapportage workshop 3 mei 1989. Wageningen, WAU, Department of Farm Economics: 6 and 39-46.

CHAPTER 4

PIEteR: a field specific production model for sugar beet growing

A.B. Smit & P.C. Struik

Abstract
PIEteR is a field specific production model for sugar beet growing. It can provide quantitative information about the technical, economic and environmental consequences of plant density, nitrogen application and harvest date. Its core is a growth model that simulates rates of emergence, growth, and root and sugar production, corrected for non-optimal water availability. Although PIEteR is not yet able to simulate extreme situations correctly, it is a good basis for the further development of a decision support system.

Keywords: sugar beet, *Beta vulgaris*, decision support, simulation model

Introduction

The many decisions made by farmers before, during and after the growing season of sugar beet (*Beta vulgaris* L.) have consequences for the yield (of roots or sugar), the quality (internal: sugar content and extractability; external: mainly tare content), financial returns and the environment (nitrogen emission). Each decision may have multiple effects and may also interact with other decisions. Moreover, each decision may be influenced by external factors such as weather conditions and soil characteristics. To improve the farmer's quantitative insight into the influence of his decisions on the final output of a sugar beet crop, we developed the growth model PIEteR [1], (Smit *et al.*, 1994).

In every sugar beet growth model the so-called 'growth point date' (GPD), the only well-defined developmental stage in this vegetative crop, must play an important role. This date is defined as the first day on which all cambial rings are visibly present in the beet (Bosch, 1986). At GPD rapid secondary beet growth starts, since the rings produce parenchymatous cell layers where sucrose can be stored. The sugar beet root contains about 4 g of sugar at GPD, an amount which rapidly increases until maturity. In practice, the GPD is assessed as

[1] PIEteR means: 'Production model for sugar beet, including Interactions between Environment and growing decisions, and their influence on the quantitative, qualitative and financial Result'.

the date on which the beet root has accumulated 4 g of sucrose. The exact date is estimated by sampling a sugar beet field three times: 1 week before GPD, at the time of GPD and 1 week after the expected GPD. GPD is calculated from the observed sugar yields by exponential or linear interpolation (L.M. Withagen, Dutch Sugar Beet Research Institute (IRS), pers. comm., 1994).

GPD nearly coincides with 'closed canopy', defined as 'the day on which the first leaves of different rows touch' (Spitters *et al.*, 1990). Therefore, GPD also indicates the turning point from the exponential to the linear production phase. Before GPD the sugar beet plants grow without (strong) above-ground interference, but not all radiation is intercepted. After GPD almost all radiation is intercepted by the crop. The earlier GPD is reached, the longer the period of full light interception will be and the greater the maximum root and sugar production. In general, the final root and sugar yields show a negative, linear correlation with GPD (Jorritsma, 1985). Linear regression analysis of national IRS data on root yield over the period 1954-1983 showed that 52% of the variance in yield was explained by GPD. A delay of GPD by 1 day resulted in a loss of about 0.6 t of fresh root yield per ha.

Tests of the prototype of PIEteR, created by Biemond *et al.* (1989), showed that PIEteR had potential, but needed improvement. This paper describes the improved version of the model.

Materials and methods

The materials for the improvement of PIEteR were Biemond's prototype version of PIEteR, a data set from the IRS, information from literature and data from field experiments in Wageningen in 1993 and 1994.

Prototype

The prototype version of PIEteR was described in Dutch by Biemond *et al.* (1989). PIEteR was written in TURBO-PASCAL (version 6).

Data sets for calibration

The IRS data set included the years 1984-1988. Each year, 250 fields, scattered over 11 uniform regions in proportion to the areas of those regions, were selected to obtain an overview of sugar beet performance. Those 250 fields were sampled 9-11 times during the growing season. The following data were collected: number of plants, (fresh) root yield and sugar content. The latter two were used to calculate sugar yield. The first 2-4 samplings were executed weekly around the moment of reaching closed canopy to assess GPD. A sampling was taken every fortnight from the beginning of August until the end of October or until fields were commercially harvested; seven times maximum. We analysed four (out of 11) regions, incorporating soil data (*lutum* [2] and organic matter content) and daily weather data (minimum and maximum temperature, total radiation and rainfall). The data set consisted of 427 fields with about 2000 variables for each field.

A field experiment, executed in Wageningen in 1993 with cv. Hilde, consisted of three nitrogen levels in four replicates. On March 30th, 21 seeds.m^{-2} were sown, with a row distance of 50 cm and a plant distance of 9.5 cm. We thinned the crop to 8-9 plants.m^{-2} on May 12th when the crop was in its eight-leaf stage. Nitrogen was applied 1 week after sowing. All data referred to in the following originate from the plots that received 100 kg N.ha^{-1}. This would have been the recommended rate, taking into account the crop's need and the residual N in the soil layer at 0-60 cm, measured in February 1993. All other practices were as standard.

Many weather data sets do not contain average daily air temperature figures but only maximum and minimum temperatures. For that reason, a module was included, developed by Van Kraalingen and Rappoldt (Goudriaan and Van Laar, 1994). It calculates 24 h air temperatures, assuming a more or less sinusoidal function. Its shape for day t is determined by the minimum and maximum temperatures of day t, the maximum temperature of day t-1 and the minimum temperature of day t+1. The module was tested against the data from the Royal Dutch Meteorological Institute in De Bilt, The Netherlands (KNMI) for the months March - June. The mean absolute difference between official and simulated daily temperature was 0.5 °C, with 99% of the variance explained.

Method of calibration

Many of the relationships hypothesised during the development of the core of PIEteR were fitted on data from the IRS set, mainly using 'NLIN' of the SAS statistical package (version 6). 'NLIN' estimated coefficients of non-linear relationships between predicted and actual root and sugar yields, applying the method of least squares. Within NLIN, the 'DUD method' or 'method of false position' was used to calculate derivatives from the history of iterations instead of analytically as in other methods. More details can be found in SAS-manuals (SAS Institute, 1988).

Method of testing

Different versions of PIEteR were tested on different independent sets of Dutch sugar beet fields. Test results were analysed by calculating the prediction error or absolute difference between observed and simulated parameter values per field, sometimes expressed in percentage of the observed value, and then averaged over all included fields. In addition, linear regression

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[2] In the model the fraction of soil particles smaller than 16 μm is used, which is 1.5 * *lutum* content.

analysis was applied to test how well the predicted values matched the observed ones. Explained variance (R^2) was used as a measure.

We tested the effect of the water balance module on the accuracy of the model through comparison of simulation results with and without water balance corrections.

Data sets for testing/validation

Available data from other authors were gathered and compared with simulation results, as follows:

1 Emergence. The soil and weather data and the sowing dates for 47 fields, scattered over seven regions and 3 years, were gathered from Smit (1989) and the Institute for Agrobiological and Fertility Research (AB-DLO) in Wageningen. We compared simulated numbers of days between sowing and emergence with observed values.

2 Growth point date. GPD of some of the fields mentioned under 4, could be derived by interpolation or (close) extrapolation. In total 13 data sets were available, including the data from the 1993 field experiment. Simulated and observed/estimated length of the period between sowing and GPD were compared.

3 Leaf stage. In 1994, the number of true leaves per plant was investigated in a field experiment in Wageningen. The collected data referred to fields under normal grower's practices.

4 Root and sugar yield. Observed and simulated data for 20 experimental fields, scattered over six regions and five years, were compared. Data sets, obtained from Snijders (1988) and Tick (1979, 1982, 1983a,b and 1987), are described by Smit and Struik (1995). The tests were carried out on final yields as well as on yields during the growing season. The fields with the smallest and largest prediction errors over the last four harvests were examined in more detail.

The general structure of the model is described below, followed by a discussion of the results of calibration and of validation tests.

The model

Figure 1 gives a schematic overview of the growth model PIEteR. The model starts its calculations on the sowing date and ends at harvest. Storage may be included in later versions. It is assumed that the farmer plants sugar beet as early as conditions allow; optimal seed bed preparation being after March 10th.

Three important phases in crop development follow:

1 the period between sowing and emergence date. The latter is defined as the day on which 50% of the seeds have produced a seedling with its cotyledons unfolded;

2 the period between emergence date and GPD. The GPD is considered to be the theoretical

onset of beet and sugar production;

3 the period between GPD and harvest date, called the 'production phase'.

In phases 1 and 2 emergence and development rates are assumed to be mainly determined by temperature. Radiation is the dominant factor in phase 3.

In all phases water balance calculations were performed to correct for suboptimal soil moisture contents. In the phases 2 and 3 regional coefficients were included to allow for regional influences that could not be explained by simple field specific parameters.

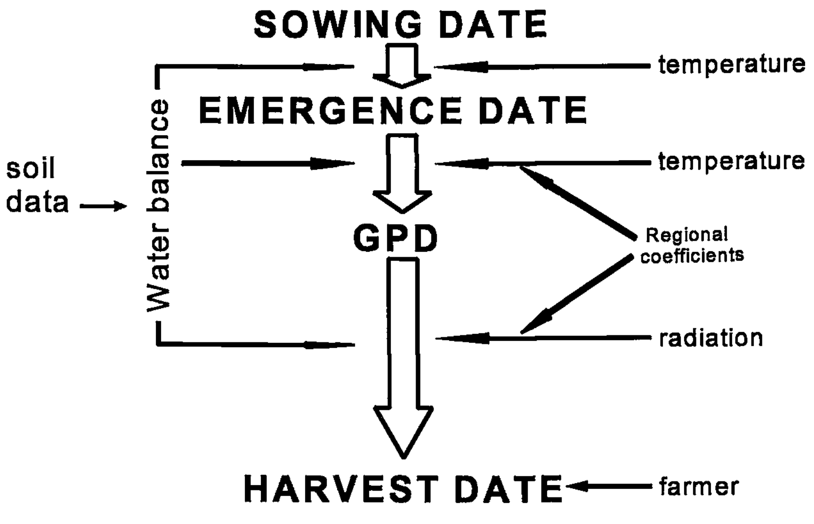


Figure 1. Schematic structure of PIEteR.

Results

Modelling results

1. Water balance. The water balance calculations are similar for all phases. The pF is calculated daily and compared with the optimal value (2.35) according to equation 1 (derived from Van Wijk *et al.* (1988)) by Verhage (1990) through regression analysis and estimation of coefficients. The daily development or production rate is multiplied by the (corrected [3]) reduction factor for that day.

[3] That is: non-linear.

$$rf[day] = \frac{1}{1 + 0.5 \exp(100 - 2 * abs(pF[day] - 2.35)) * 0.05 * \log(abs(pF[day] - 2.35)))} \quad (1)$$

in which

rf[day]	=	reduction factor for suboptimal soil moisture content	[-]
pF[day]	=	pF-value for the rooted soil layer [4]	[-]

2. *Phase 1.* The length of the first phase, the emergence phase, is assumed to be negatively and linearly correlated with the difference between the average daily temperature and a so-called basic temperature (Equation 2). Seeds do not emerge below the basic temperature. Above a certain upper limit, t_{max}, a temperature increase does not result in a faster emergence. In The Netherlands, t_{max} does not occur in the normal sowing season (March - April).

$$dt_{sum} = (temp[day] - t_{base}) - 0.5 * (1 - \sqrt{rf[day]}) * temp[day] \quad (2)$$

in which

dt_{sum}	=	daily increase of temperature sum	[°C]
temp[day]	=	average air temperature, if in the proper range [tbase, tmax]	[°C]
t_{base}	=	basic temperature for emergence	[°C]
rf[day]	=	water balance reduction factor (equation 1)	[-]
t_{max}	=	temperature above which temperature increase does not accelerate the emergence process	[°C]

Non-linear estimations for tbase and tmax were 3.0 and 34.3 °C, respectively (Verhage, 1990).

Since the sowing depth is only about 2 cm, the soil temperature can be estimated by the more widely available air temperature. According to Van Wijk *et al.* (1988), the time between sowing and emergence dates can be expressed as an (air) temperature sum. The date of emergence is reached when the thermal time, the sum of the daily contributions of the average air temperature above the basic temperature, reaches the value of 89 °C.days. Corrections were made for suboptimal soil moisture contents, delaying the simulated emergence process. Not temperature itself, but the daily contribution to the required temperature sum changed with suboptimal soil moisture content.

From the day of sowing onwards, the water balance procedure in PIEteR estimated the moisture status of the soil daily (Verhage, 1990; after Belmans *et al.*, 1983). Emergence may

[4] Dynamic calculation of the rooted soil layer is part of the water balance module.

be hindered when the seeds are not placed on the more compact layer under the seed bed and/or when the seed bed is thinner than 2 cm or thicker than 4 cm (Jorritsma, 1985). Emergence may be impeded by factors such as total lack of moisture in the seed bed caused by dry conditions or mechanical resistance through crust formation, observed in fields with certain soil types after heavy rainfall, followed by strongly drying weather conditions (Bosch, 1986; Jorritsma, 1985). The model does not correct or account for such problems with emergence.

3. *Phase 2.* The length of the second phase is likewise assumed to be determined by the daily contribution of air temperature, corrected for suboptimal soil moisture contents. The temperature sum for emergence is valid for all soil types and regions in The Netherlands. The temperature sum for GPD, however, has - for unknown reasons - different values for different regions.

The dates on which the crop reaches leaf stages 1 - 10, were modelled using the data from the 1993 field experiment. Thermal time for each stage was calculated. An expolinear relationship between leaf stage and temperature sum was derived from data of the experiment (Goudriaan and Monteith, 1990), as shown in equation 3:

$$Leaf\ stage = (C_m / R_m) * \ln(1 + \exp[R_m(t_{sum} - t_{sum_b})]) \tag{3}$$

in which

leaf stage	=	average number of true leaves per plant	
C_m	=	maximum rate of leaf formation	[leaf.(°C.days)$^{-1}$]
R_m	=	maximum relative rate of leaf formation	[(°C.days)$^{-1}$]
t_{sum}	=	sum of daily average temperatures (corrected for basic temperature = 3.0 °C), calculated from emergence day onwards	[°C.days]
$t_{sum,b}$	=	temperature sum that marks the turning point from exponential to linear growth phase	[°C.days]

Table 1 shows the results of the expolinear approach.

According to the model, it took 426 °C.days from sowing to the ten-leaf stage. GPD marks the end of phase 2. The temperature sum to reach this date ranged from 576 to 687 °C.days. By definition, about 4 g of sugar is found per beet on GPD, which is about 7% of the fresh beet weight.

Table 1. Results of a non-linear least squares procedure for estimation of the coefficients in equation 3.

Parameter [1]	Estimated value	95%-confidence interval	
		Lower limit	Upper limit
C_m (leaf.(°C.days)$^{-1}$)	0.032	0.029	0.036
R_m ((°C.days)$^{-1}$)	0.012	0.010	0.015
$t_{sum,b}$ (°C.days)	119	85	152

[1] For explanation of acronyms: see equation 3

The exact fresh root yield on GPD depends on the weather conditions at that time and cannot be predicted accurately. To solve this problem, the term 'day of onset' was introduced: the day that root and sugar production starts; this theoretical term allows an accurate prediction of GPD and, as a consequence, of root and sugar yields. The same procedure (set of equations to predict daily productions of root and sugar) used after GPD was applied to count back from GPD and calculate the day that the sugar yield would be nil, the 'day of onset'. Root yield was also set at nil on that day. From the day of onset onwards, the calculations moved forward in time again, and both root and sugar production were predicted.

4. Phase 3. After GPD (with a closed canopy) production was assumed to be mainly determined by the daily amount of total radiation. Non-optimal soil moisture contents were again corrected for. Two sets of 'efficiency equations' calculated the transition from total (not intercepted) radiation into root and sugar respectively. Figure 2 shows the efficiency observed from the IRS data set [5]. During the season, the efficiency of fresh root production decreased, whereas the efficiency of sugar production increased. Milford and Thorne (1971, 1973) indicated that the efficiency in autumn was influenced by temperature. This was only true for the sugar content on a fresh root basis, but not for the total sugar production, which was directly predicted by our model.

The set of equations for fresh root production were similar to those for sugar production (4 and 5). Both fresh root and sugar efficiency equations contained four coefficients. Estimation results are listed in Table 2. The 95%-confidence intervals are wide, which is not unusual for a data set of this kind.

[5] For practical reasons GPD was set at June 21st, a reasonable date for average Dutch circumstances; radiation data for Wageningen, 1993, were used. Water availability was assumed to be non-limiting.

$$d_{sugar} = reg_{sug} * sug_{eff} * glorad * (1 - 0.5 * (1 - \sqrt{rf[day]})) \tag{4}$$

in which

d_{sugar}	=	daily sugar production	[$g.m^{-2}.day^{-1}$]
reg_{sug}	=	correction factor for regional yield level	[-]
sug_{eff}	=	efficiency of total radiation into sugar	[$g.MJ^{-1}$]
glorad	=	total radiation	[$MJ.m^{-2}.day^{-1}$]
rf[day]	=	water balance reduction factor (equation 1)	[-]
day	=	time (days after March 1st)	[day]

and

$$sug_{eff} = sd * \frac{sa^2 * \sin(sb * ((day + 59) - gpd) + sc)}{sa + (1 - sa) * \exp(-\frac{sb * ((day + 59) - gpd) + sc}{sa})} \tag{5}$$

in which

sug_{eff}	=	efficiency of conversion of total radiation into sugar	[$g.MJ^{-1}$]
gpd	=	growth point date (day of year)	[day]
sa	=	coefficient to be estimated	[-]
sb	=	coefficient to be estimated	[day^{-1}]
sc	=	coefficient to be estimated	[-]
sd	=	coefficient to be estimated	[$g.MJ^{-1}$]

Only national equations could be used in the prototype of PIEteR, because of the limitations of the IRS data set. Therefore, regional yield levels were calculated from regional IRS data over the period 1984 - 1988 and incorporated into the daily root and sugar production equations to correct for regional yield potentials.

The basic version of PIEteR did not correct for plant density and nitrogen level.

Test results

1. Emergence, GPD and leaf stage. It took an average of 15 days for the beets to emerge according to countings, whereas PIEteR predicted 16 days; the mean prediction error and the explained variance were 1.6 days and 84.1%, respectively (Figure 3).

The mean simulated period between the sowing date and GPD was 76 days, whereas 73 days had been observed; the mean prediction error over 13 fields was 4.2 days; the explained variance was 83.4% (Figure 4).

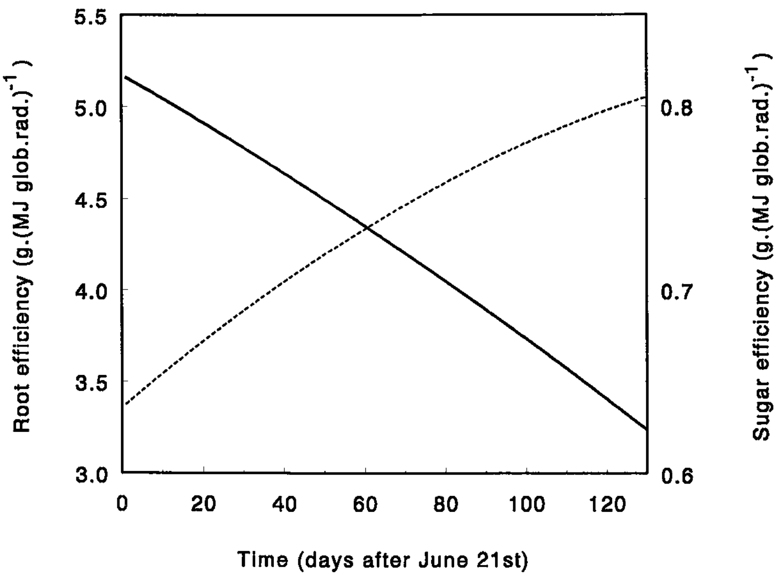


Figure 2. Development over time (after GPD) of the efficiency of fresh root and sugar production.

Table 2. Results of non-linear estimation of root (ra, rb and rc) and sugar efficiency coefficients (sa, sb and sc); rd and sd were set at 1 and on beforehand. See equations 4 and 5.

Coefficient	Estimated value	95%-confidence interval	
		Lower limit	Upper limit
ra	0.704	- 31.7	33.1
rb (day^{-1})	0.003	- 0.102	0.107
rc	2.3	- 25.9	30.5
rd ($g.MJ^{-1}$)	1		
sa [1]	0.0826		
sb (day^{-1})	0.0036	- 0.0086	0.0157
sc	0.93	0.46	1.40
sd ($g.MJ^{-1}$)	1		

[1] Since different combinations of sugar coefficients were possible, sa was set at one of the optimal values before estimating sb and sc.

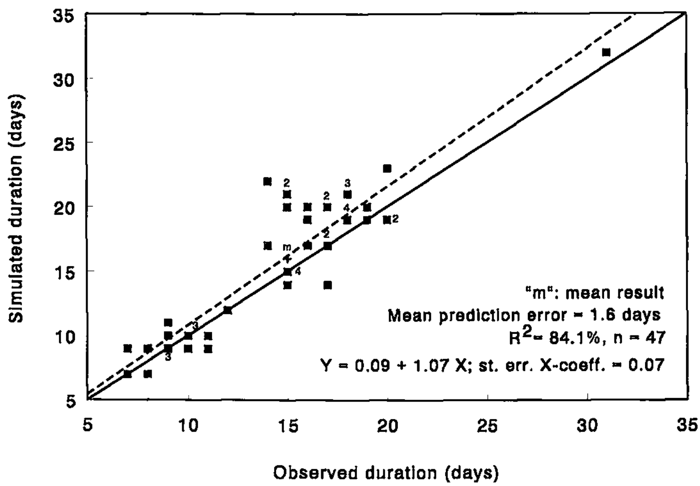


Figure 3. Simulated duration of emergence phase versus observed duration ('2', '3', '4': number of observations with same coordinates). (symbols: ___ : Y = X line, ...: regression line)

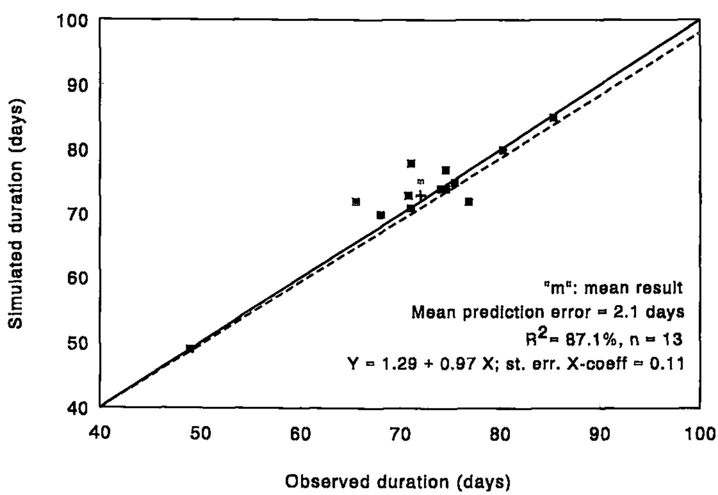


Figure 4. Simulated versus observed duration of the period between sowing date and GPD. (symbols: ___: Y = X line, ...: regression line)

The leaf stage was predicted with a mean error of 0.3 leaves or 9.5%, and an explained variance of 99% (Figure 5).

2. *Root and sugar yield.* Results of the tests on final root and sugar yields are shown in Figures 6A-B. Fresh root production averaged 6.50 $kg.m^{-2}$, whereas the model predicted 6.44 $kg.m^{-2}$. The mean prediction error was 7.8% of the observed yield and the explained variance was 62.1%. The observed sugar yield was 1.12 $kg.m^{-2}$, slightly more than the predicted value (1.09 $kg.m^{-2}$). The mean prediction error was 8.2%, whereas 70.5% of the variance was explained.

Without water balance corrections PIEteR simulated 6.63 and 1.12 $kg.m^{-2}$ root and sugar, respectively. The respective prediction errors and explained variances were 7.7% and 8.4%, and 58.8% and 65.4%.

Every field was harvested several times during the growing season. When the last four harvests per field (in total, 20*4=80 observations) were analysed instead of the final harvest, the mean prediction error increased to 13% and 16% for root and sugar yield respectively. At the same time the explained variance increased to 74% and 87% respectively. In the analysis of all observations the errors increased to 19% and 32% respectively, partly due to relatively

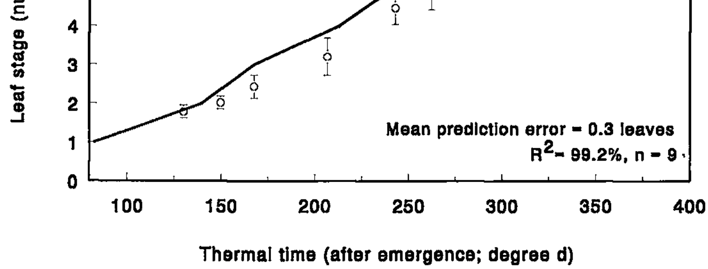
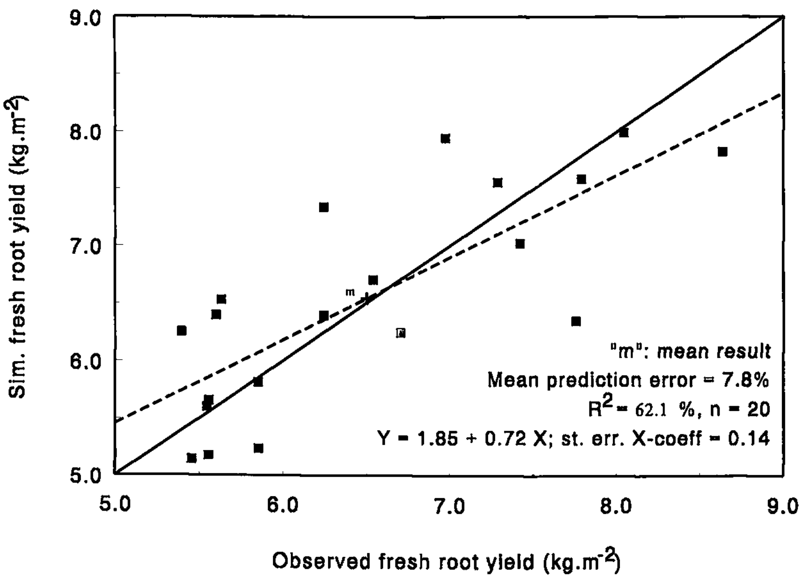


Figure 5. Simulated and observed leaf stages versus thermal time. (symbols: o: observed, ⊥ T: standard error of means, ___: simulated)

A



B

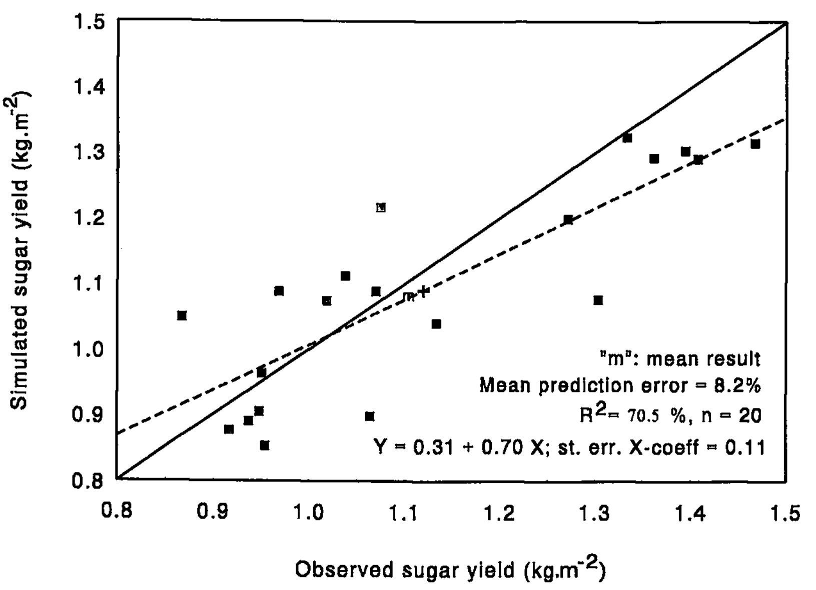


Figure 6. Simulated versus observed yields. A: Fresh root yield; B: Sugar yield. (symbols: ___: Y = X line, ...: regression line)

low yields in the first month after GPD. R^2 increased to 91% and 94%, respectively.

Figures 7A and B show the root and sugar production of two individual fields during the season. The simulation of production at field 18 (Figure 7A) was relatively good, that of field 1 (Figure 7B) relatively poor.

Discussion

Modelling results

The observations, modelling and tests on leaf stage were all carried out on (data from) heavy river clay soils. Van Wijk *et al.* (1988) used 89 °C.days for the temperature sum between sowing and emergence dates for all soil types, assuming that differences in emergence were sufficiently explained by differences in the moisture content of the soil. The relationships between leaf stage and temperature sum may, however, be different for different soil types, just as temperature sums for GPD are different for different regions.

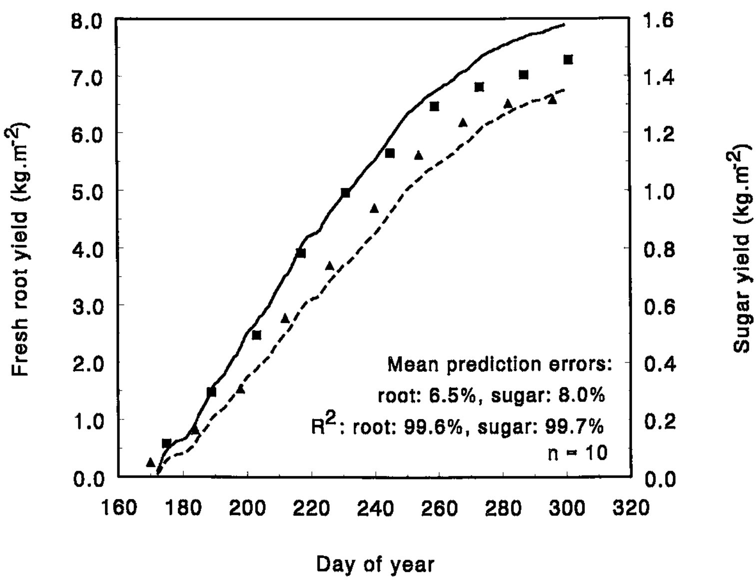
Water balance calculations were included in the simulation of emergence date, leaf stage and GPD. These corrections were sufficient for a good prediction of emergence date, but in the case of GPD and yield, regional coefficients had to be included for accurate predictions. Apparently other factors than the water status of the soil were involved. More detailed research is necessary to make PIEteR fully field specific.

Efficiency values for root and sugar production gradually change over time, without clear breaking points (Struik, 1989). Milford and Thorne (1973) suggested that sugar beet does not show 'ripening', defined as an increase in sugar accumulation relative to non-sugar dry matter. Data on dry root yield were not fully available in the IRS data set, but in the 1993 field experiment the content of sugar in the dry matter indeed remained constant at about 75% from the end of July onwards.

Spitters *et al.* (1990), who developed a regional model without any field specific correction, found similar light use efficiency curves as given in Figure 2, although in their study sugar efficiency decreased from the end of September onwards. They found a maximum value of 0.9 g sugar.(MJ total radiation)$^{-1}$. Smit (1990) reported a constant value for sugar production efficiency of 1.05 g sugar.(MJ intercepted radiation)$^{-1}$ on newly reclaimed (fertile) land. The average sugar efficiency in Figure 2 is 0.74 g sugar.(MJ total radiation)$^{-1}$. Corrected for regional yield level this equals 0.87 g sugar.(MJ total radiation)$^{-1}$. Smit (1990) calculates light interception, but in the model of Spitters *et al.* (1990) and in PIEteR, daily productions are calculated from total radiation. Light use efficiency changes in time with changing interception rates, which are implicitly included.

Haverkort and Schapendonk (1994) found that the light use efficiency is relatively conservative in comparison to the amount of intercepted radiation. Consequently, the root and

A



B

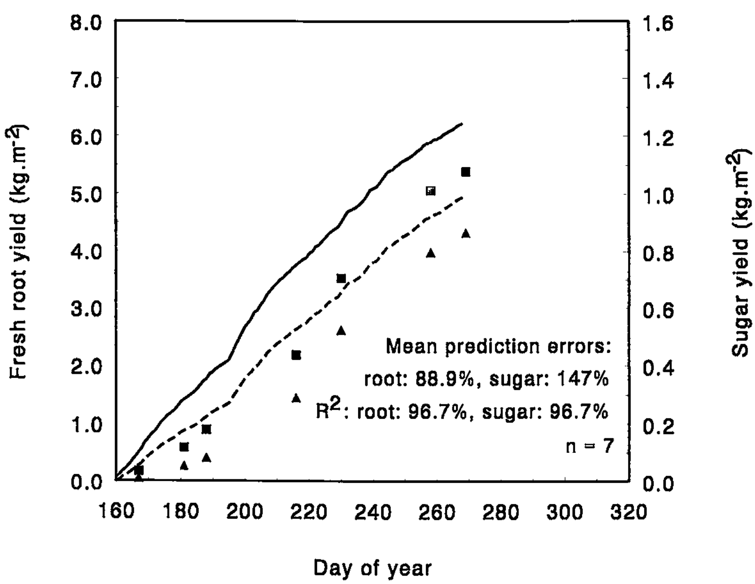


Figure 7. Simulated and observed fresh root and sugar yields versus time. A: field 18; B: field 1. (symbols: ■: observed root yield, ___: simulated root yield, ▲: observed sugar yield, - -: simulated sugar yield)

sugar production efficiency functions in PIEteR may still be valid when minor stresses occur, so that stress reduction factors can be included in a relatively simple way.

The introduction of regional correction factors for yield level (equation 4) was necessary because of an incomplete data set for calibration; however, a field specific estimation of yield level would have been better, since variation between fields within a region is not fully due to variations in the soil characteristics *lutum* and organic matter contents. The latter were included in this version of PIEteR to make daily water balance calculations possible, but they did not influence the predictions in the sense of chemical soil fertility.

Test results

Simulated emergence was about 1 day later than observed emergence. An accurate simulation of emergence date is important for three reasons. Firstly, it contributes to proper simulation of leaf stages, GPD and yields. Secondly, when pre-emergence herbicides cannot be applied directly after sowing because of rainfall, the (correctly) predicted emergence date indicates how long the herbicide application can be postponed without damage to emerging plantlets. Thirdly, a significant difference between observed and simulated emergence dates on a particular field may indicate that there are abnormal circumstances, such as crust formation, which the emergence module does not account for.

The leaf stage module checks whether the development of the crop continues normally. Moreover, leaf stage is relevant for the timing of mechanical or chemical weed control. Under dry conditions, full-width harrowing can be applied from the 4-6 leaf stage and onwards, completing the effects of applied chemicals (Wevers, 1994). Schäufele (1992) suggested that chemical weed control in sugar beet should be related to damage thresholds as commonly practised in cereals. Such thresholds would require input on crop development, e.g. leaf stage.

Initially, the number of true leaves increased exponentially. From about the four-leaf stage onwards, a linear increase would describe the development quite well. In the 1993 field experiment, air temperature was a good input parameter to simulate the duration of the period between sowing and four-leaf stage, but soil temperature, measured at a depth of 5 cm at 0800 h, gave better results. Apparently, the sugar beet plant is mainly influenced by soil temperature until it reaches the four-leaf stage; air temperature then becomes the dominant factor. Sensitivity to frost and insect damage decreases after the four-leaf stage. If a plant survives this stage, the first vulnerable period in sugar beet development has been overcome (Bosch, 1986). In the test, all stages were simulated reasonably well (Figure 5).

The average observed length of the period between sowing and GPD was 76 days, a finding in agreement with Spitters *et al.* (1990), who analysed regional data over the period 1981 - 1986. Simulated GPD was only 1 day too late on average, and the prediction was sufficiently accurate. Differences between observed and simulated GPD were not correlated with differences between observed and simulated root and sugar yields.

Root and sugar yields were also accurately predicted: differences between simulated and observed values were below 10%. Kollig (1993) created a neural network model for sugar beet and defined mean differences in a slightly different way than in this study. In the case of this study re-calculated differences were 9.8% for both root and sugar yield. Kollig found a mean difference of 4.2% for root yield, but he used many more fields (1171) and used 60% of them to improve the network.

Mean differences of 5% for regional predictions are not unusual (Van Evert, 1988; Müller and Rössner, 1992), but compensation between fields in the same region may occur. When, instead of the final harvest, the last four harvests per field were analysed, the errors (about 15%) were still acceptable. At the same time, the explained variance increased; this was partly due to the regression method, which was influenced by the number of observations. Taking all observations during the growing season into account, R^2-values of more than 90% were found, which indicated that the general shapes of the observed and simulated production curves were similar (Figure 7). However, the observed curves had a stronger s-shape than the simulated ones. Field 1 (Figure 7B) had a low plant density (4.1 plants.m^{-2}), which may explain the low observed yields throughout the season.

A Polish model at a regional level, including a climatic water balance, explained 79% of the variance of sugar yield in a test over seven regions and 10 years (Spoz-Pac, 1990). PIEteR explained only 70%; other sources of variance could be plant density and nitrogen level, which would probably compensate at a regional level.

PIEteR tended to overestimate low yields and to underestimate high ones (Figure 6). Although water balance corrections improved the accuracy of the model, PIEteR was not yet able to correct adequately for very favourable or very unfavourable conditions partly determined by local soil characteristics.

PIEteR was based on data of Dutch sugar beet fields. Because final yield assessment was at or before the end of October the model predictions were limited to October 31st. However, some farmers harvest in November, assuming that such a delay is profitable. Extending the calculations to November would involve extrapolation of the efficiency functions for both root and sugar production; this would be risky, since low temperature and radiation levels in this period could greatly change the efficiency functions (Spitters *et al.*, 1990).

The descriptive character of PIEteR restricts its use to Dutch circumstances. For use in other Western European countries several parameters would need re-estimation based on such specific data as production efficiency coefficients, temperature sums for the period between emergence and GPD, and regional yield level.

The growth model discussed, the beginning of the bio-economic production model PIEteR, will be used as a basis for further development in which plant density, nitrogen level and delayed harvest may be important factors. The inclusion of a water balance module, based on field specific soil characteristics, and of emergence and leaf stage modules is a great improvement over the model of Spitters *et al.* (1990); their model and PIEteR were both based on simple causal relationships between temperature sums and development, and radiation and production.

Zusammenfassung

PIEteR: Ein feldspezifisches Produktionsmodell für den Zuckerrübenanbau

PIEteR ist ein feldspezifisches Produktionsmodell für den Zuckerrübenanbau. Es stellt quantitative Informationen für technische, ökonomische und Umweltkonsequenzen der Bestandesdichte, der Stickstoffanwendung und des Erntetermins zur Verfügung. Seine Grundlage ist ein Wachstumsmodell, mit dem Auflaufraten, Entwicklung sowie Wurzel- und Zuckerproduktion, korrigiert für nichtoptimale Wasserverfügbarkeit, simuliert werden. Die Veröffentlichung beschreibt die Basisversion von PIEteR, in der nicht für Bestandesdichte und Stickstoffwirkungen korrigiert wird.

PIEteR verwendet Temperatursummen, um das Auflaufdatum, die Blattentwicklung und das 'growth point date' (GPD, das etwa mit dem Bestandesschluß zusammenfällt) vorauszusagen. Kurz vor GPD beginnt Wurzel- und Zuckerproduktion. Wurzel- und Zuckereffizienzen sind Funktionen der Zeit nach GPD, wobei die Strahlungsmenge in tägliche Wurzel- und Zuckerproduktion umgesetzt wird. Auflaufen, Entwicklung und Produktionsraten werden täglich für suboptimale Bodenwassergehalte korrigiert.

Tests ergaben, daß PIEteR Auflaufdaten, Blattentwicklung, GPD sowie Wurzel- und Zuckerproduktion während der Wachstumsdauer genau voraussagte. PIEteR ist nicht in der Lage, extreme Bedingungen korrekt zu simulieren, gibt aber eine gute Grundlage für die weitere Entwicklung eines Entscheidungen unterstützendes Systems.

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References

Belmans, C., J.G. Wesseling & R.A. Feddes, 1983. Simulation model of the water balance of a cropped soil: SWATRE. *Journal of Hydrology* **63**, 271-286.

Biemond, T., H.J. Greve, T. Schiphouwer & A.J. Verhage, 1989. PIEteR, semi green-box produktiemodel suikerbieten. Wageningen, WAU, Department of Farm Economics, 31 pp.

Bosch, H. (ed.), 1986. Teelt van suikerbieten. Lelystad, The Netherlands, CAD-AGV/ PAGV, Teelthandleiding nr. 21, 100 pp.

Evert, van, F.K., 1988. Onderzoek naar de toepassingsmogelijkheden van een gewasgroeimodel voor suikerbieten in verband met prognotisering van de bietenoogst. Diemen, CSM.

Goudriaan, J. & H.H. van Laar, 1994. Modelling potential crop growth processes. Dordrecht, Kluwer Academic Publishers, 238 pp.

Goudriaan, J. & J.L. Monteith, 1990. A mathematical function for crop growth based on light interception and leaf area expansion. *Annals of Botany* **66**, 695-701.

Haverkort, A.J. & A.H.C.M. Schapendonk, 1994. Crop reactions to environmental stress factors. In: P.C. Struik, W.J. Vredenberg, J.A. Renkema and J.E. Parlevliet (eds.). Plant production on the threshold of a new century. Proceedings of the international conference on the occasion of the 75th anniversary of the Wageningen Agricultural University, Wageningen, The Netherlands, June 28 - July 1, 1993. Developments in plant and soil sciences, 61. Dordrecht/Boston/London, Kluwer: 339-347.

Jorritsma, J., 1985. De teelt van suikerbieten. Zutphen, Terra. Groene Reeks, 286 pp.

Kollig, M., 1993. Zur Abbildung komplexer Systeme mittels neuronaler Netze. *Agrarwirtschaft* **42**, 10, 367-372.

Milford, G.F.J. & G.N. Thorne, 1971. Effects of temperature and radiation at different stages of growth of sugar beet. Rothamsted, UK, Report of Rothamsted Experimental Station for 1971, part I, 101-103.

Milford, G.F.J. & G.N. Thorne, 1973. The effect of light and temperature late in the season on the growth of sugar beet. *Annals of applied Biology* **75**, 419-425.

Müller, H.J. & H. Rössner, 1992. Systeme der Erntevorschätzung in Österreich. In: Proceedings IIRB-Congress, 12-13 February 1992. Brussels, IIRB: 211-222.

SAS Institute, 1988. SAS Language Guide. Release 6.03 Edition. Cary, USA, 1042 pp.

Schäufele, W.R., 1992. Unkrautbekämpfung in Zuckerrüben nach Schadenschwellen. In: Proceedings IIRB-congress 12-13 February 1992. Brussels, IIRB: 353-359.

Smit, A.L., 1989. Overzaaien van suikerbieten. Lelystad, The Netherlands, PAGV-verslag nr. 91, 78 pp.

Smit, A.L., 1990. Teeltvervroeging bij suikerbieten. Een verslag van uitgevoerde proeven op het PAGV in de periode 1985 t/m 1988 in het kader van project 56.4.14. Lelystad, The Netherlands. PAGV-verslag 100, 52 pp.

Smit, A.B., J.H. van Niejenhuis & P.C. Struik, 1994. Introduction to a bio-economic production model for sugar beet growing. In: P.C. Struik, W.J. Vredenberg, J.A. Renkema and J.E. Parlevliet (eds.). Plant production on the threshold of a new century. Proceedings of the International Conference on the occasion of the 75th Anniversary of the Wageningen Agricultural University, Wageningen, The Netherlands, June 28 - July 1, 1993. Developments in plant and soil sciences, 61. Dordrecht/Boston/London, Kluwer: 115-122.

Smit, A.B. & P.C. Struik, 1995. The first step towards a decision support system for sugar beet growing: selection of a basic model. *Journal of Agronomy and Crop Science* **175**, 213-220.

Snijders, H., 1988. Proefveldverslag van N-bemesting op suikerbieten, met een nadere beschouwing van de N-balansmethode voor advisering van N-bemesting op suikerbieten. Wageningen, WAU, Department of Soil Science and Plant Nutrition, MSc-thesis, 30 pp. (plus appendices).

Spitters, C.J.T., B. Kiewiet & T. Schiphouwer, 1990. A weather-based yield-forecasting model for sugar beet. *Netherlands Journal of Agricultural Science* **38**, 731-735.

Spoz-Pac, W., 1991. Agrometeorologiczna metoda prognozowania plonu burakow cukrowych (An agrometeorological method of forecasting the yield of sugar beet). Zeszyty naukowe Akademii Rolniczej im Hugona Kollataja w Krakowie (Scientific papers of the Agricultural University in Krakow) **27**, 205-216.

Struik, P.C., 1989. Enkele inleidende opmerkingen over simulatie van groei, produktie en kwaliteit van de suikerbiet. In: T. Biemond (ed.). *Produktiemodel suikerbieten.* Rapportage workshop 3 mei 1989. Wageningen, WAU, Department of Farm Economics: 25-28.

Tick, J.J., 1979. De groei van de suikerbiet in 1978. Lelystad, The Netherlands, PAGV. Intern Verslag nr. 87, 22 pp.

Tick, J.J., 1982. De groei van de suikerbiet in 1981. Lelystad, The Netherlands, PAGV. Interne Mededeling nr. 238, 33 pp.

Tick, J.J., 1983a. De groei van de suikerbiet in 1982. Lelystad, The Netherlands, PAGV. Interne Mededeling nr. 268, 36 pp.

Tick, J.J., 1983b. De groei van de suikerbiet in 1983. Lelystad, The Netherlands, PAGV. Interne Mededeling nr. 316, 36 pp.

Tick, J.J., 1987. Droge-stof-productie en -distributie bij suikerbieten en voederbieten in relatie tot de hoeveelheid straling in de jaren 1978, 1981, 1982 en 1983. Lelystad, The Netherlands, PAGV. Interne mededeling nr. 592, 20 pp.

Verhage, A.J., 1990. VSIM, een vochtsimulatieprogramma voor de Nederlandse akkerbouw. Wageningen, WAU, Department of Farm Economics, MSc-thesis, 31 pp. (plus appendices).

Wevers, J.D.A., 1994. Onkruidbestrijding nog minder chemie? *Maandblad Suiker Unie* **28**, 4, 13-15, IRS-informatie.

Wijk, van, A.L.M., R.A. Feddes, J.G. Wesseling & J. Buitendijk, 1988. Effecten van grondsoort en ontwatering op de opbrengst van akkerbouwgewassen. Een evaluatie over 30 jaren van de opbrengst van aardappelen en zomergraan op acht bodemprofielen bij vijftien combinaties van ontwateringsdiepte en -intensiteit. Wageningen, The Netherlands. ICW-rapporten (nieuwe serie) 31, 130 pp.

CHAPTER 5

Modelling the influence of plant density on yield, sugar content and extractability of sugar beet

A.B. Smit, P.C. Struik & J.H. van Niejenhuis

Summary

Internal quality is an important parameter in PIEteR, a bio-economic growth model for sugar beet growing. It is determined by sugar content and extractability of sugar. The course of extractability parameters was modelled as a function of time after canopy closure. Both yield and quality predictions were corrected for plant density effects.

Plant density corrections improved the predictions of root and sugar yield. An accurate prediction of internal quality parameters remained difficult due to the complexity of the relationships between quality and nitrogen supply. The prediction of the operating receipts was improved, so that the ability of PIEteR for accurate decision support increased.

Résumé

La qualité interne constitue un paramètre important du modèle PIEteR, un modèle bio-économique élaboré pour la culture de la betterave sucrière. Cette qualité est déterminée par la taux et l'extractabilité du sucre. L'évolution de l'extractabilité a été modelée comme une fonction temps à partir du moment de la fermeture du foliage. Les prédictions de rendement et de qualité interne sont corrigées en fonction des variations de densité de plantation.

Ces corrections améliorent les prédictions de rendement en racine et de rendement en sucre. Prédire la qualité interne avec précision reste difficile en raison de la complexité des relations entre la qualité et la fertilisation azotée. L'amélioration de la prédiction des recettes augmente la capacité du modèle PIEteR à seconder les cultivateurs dans leurs prises de décisions.

Zusammenfassung

Die innere Qualität ist ein wichtiger Parameter in PIEteR, einem bio-ökonomischen Produktionsmodell für den Zuckerrübenanbau. Diese besteht aus dem Zuckergehalt und der Extrahierbarkeit des Zuckers. Der zeitliche Verlauf dieser inneren Qualitätsparameter wurde für die Zeitdauer nach dem Reihenschluß modelliert. Die Ertrags- und Qualitätsvorhersagen wurden für die Effekte der Pflanzendichte korrigiert.

Diese Korrekturen verbesserten die Vorhersagen des Wurzel- und Zuckerertrages. Die

innere Qualität war jedoch aufgrund der komplexen Beziehungen zwischen Qualität und Stickstoffversorgung weiterhin schwer vorherzusagen. Die Vorhersage der finanziellen Erträge wurde verbessert, so daß das Programm PIEteR die Entscheidungen der Landwirte besser unterstützen kann.

Introduction

The production model PIEteR [1] was developed as a basis for a decision support system in sugar beet (*Beta vulgaris* L.) growing. So far, it focused on root and sugar yields (Smit and Struik, 1995b). Modelling of quality, however, is crucial for a production model which is a part of a bio-economic decision support system, because quality is important for the price per unit of beet or sugar delivered.

The quality of sugar beet comprises two main aspects: the external and the internal quality. The external quality mainly refers to tare, not elaborately discussed here. The internal quality is determined by content and extractability of sugar. Until now sugar content has been calculated from the predicted root and sugar yields; extractability has not been predicted at all (Smit and Struik, 1995b).

The extractability index of sugar beet is a measure for the relative amount of crystalline white sugar produced per unit of sugar present in the beet (O'Connor, 1983). The non-extractable sugar remains mainly in the molasses, a byproduct with a relatively low price. The extractability of sugar in the beet is positively correlated with sugar content and is negatively correlated with impurities (Van der Beek and Huijbregts, 1986). Variation in sugar content explains 50% of the variation in the extractability index. The amount of α-amino-N, potassium (K) and sodium (Na) accounts for 50 - 90% of the negative effect of impurities on the extractability (Last and Draycott, 1977). Equation 1, derived by Van Geijn *et al.* (1983), is used in the Dutch sugar industry as a standard measure for extractability.

$$Extr = 100 - (0.342 * (K + Na) + 0.513 * (\alpha N - 17)) \tag{1}$$

in which

Extr	=	Extractability index of sugar beet	[-]
K	=	K content	[mmol.(100 g sugar)$^{-1}$]
Na	=	Na content	[mmol.(100 g sugar)$^{-1}$]
αN	=	α-amino-N content	[mmol.(100 g sugar)$^{-1}$]

[1] PIEteR means: 'Production model for sugar beet, including Interactions between Environment and growing decisions, and their influence on the quantitative, qualitative and financial Result'.

100	=	Value of Extr if impurities are absent	[-]
0.342	=	The amount of sugar per unit K+Na which cannot be extracted [2]	[g.(mmol K+Na)$^{-1}$]
0.513	=	The amount of sugar per unit α-amino-N which cannot be extracted [3]	[g.(mmol α-amino-N)$^{-1}$]

The minimum value of α-amino-N content in the equation is 17 mmol.(100 g sugar)$^{-1}$. Note that impurities are expressed on the basis of 100 g sugar and not on the basis of fresh weight of the beet.

Oltmann *et al.* (1984) valued the general influence of growing conditions (soil, climate) on internal quality at 37%, that of year effects (weather conditions) at 11%, that of nitrogen fertility at 20% and those of plant density and variety both at 16% of the total variation. In this paper, the influence of plant density is described, corrected for regional growing conditions. In another paper we focus on the effects of nitrogen supply (Smit *et al.*, 1995).

Plant density in spring is determined by row and plant distances (in Dutch circumstances 50 cm and about 18.3 cm, respectively), field emergence (more than 80% on average in The Netherlands but with deviations to substantially lower values (Van der Beek, 1993a)), including plant survival until the 4-leaf stage. This study is based on the modern practice to drill sugar beet to-a-stand, assuming that thinning is no longer applied.

Märländer (1990) was selected from different references on plant density effects for further analysis. He concluded from experimental data from Germany over the period 1980 - 1988 with plant densities in the range of 3.5 - 11.0 plants.m^{-2}, that root and sugar yields were maximum at 9.2 and 9.5 plants.m^{-2}, respectively. Sugar content was maximum at 10.7 plants.m^{-2}. (K + Na) and α-amino-N contents decreased with increasing plant density. The extractability index according to Van Geijn *et al.* (1983) increased with increasing plant density within the given range.

In this paper the internal quality parameters are modelled as a function of time and effects of plant density on root and sugar yields and quality parameters are described; relationships are tested on experimental data.

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[2] 1 mmol of K+Na is accompanied by 1 mmol (or 0.342 g) of sugar.

[3] 1 mmol of α-amino-N is (above the limit of 17 mmol.(100g sugar)$^{-1}$) accompanied by 1.5 mmol of sugar.

Materials and methods

1. Modelling

Sugar content

Sugar content was calculated from predicted root and sugar yields.

Extractability index

Field specific data during the season and regional means on (K + Na) and α-amino-N contents on sugar basis over the period 1984 - 1988, gathered by the Dutch Sugar Beet Research Institute (IRS), were used to model the extractability index as a function of time (days after growth point date (GPD)), applying equation 1. Modelling on fresh root basis and compensating for sugar content was possible as well, but this indirect method would have resulted in greater risks of inaccurate predictions of the extractability index. More information on GPD (approximately the day of canopy closure) and the IRS data is given by Smit and Struik (1995b,a, respectively).

Plant density effects

Van der Beek and Jager (1979) executed and analysed field experiments, which were especially designed to study the influence of plant density in spring on yield and quality of sugar beet. We re-analysed their data (either original data obtained from the authors or data derived from their graphs) and derived relationships between plant density on the one hand and different yield and quality parameters on the other with the non-linear estimation procedure 'NLIN' in SAS (1988).

The source data originated from different varieties, fields, regions, soil types and years. Therefore, the observed output data were expressed as a percentage of the mean value of the respective experiment as applied by Märländer (1990). The data covered a range of 4.3 - 18.4 plants.m^{-2}, a much wider range than in Märländer's data set. Consequently, the comparison of both sets of curves was not perfect.

Märländer had derived curves for relative Na and K contents separately; these were combined in a curve for total (K + Na) content in order to compare his results with our (K + Na) curve. Märländer's curve was derived by assuming that K would make up 91% of this sum (derived from IRS data). The relative extractability index could not be calculated: since our data set only contained data on relative (K + Na) and α-amino-N contents, equation 1 could not be applied.

Because of incomplete data on (K + Na) and α-amino-N contents in Van der Beek and Jager (1979), we decided to include Märländer's plant density corrections in PIEteR; this was not necessary for root and sugar yields and sugar content.

PIEteR

The derived functions were included in PIEteR, which is written in TURBO-PASCAL, version 6.

2. Tests

The regression equations for different yield and quality parameters versus plant density were compared with those, derived by Märländer (1990).

Root and sugar yields, sugar content and the extractability parameters were predicted with and without plant density corrections. In addition, the operating receipts per ha of sugar beets were calculated in order to evaluate the integrated effect of the plant density module on the farm economic predictions for the aim of decision support. More information on the sales system is given in Table 1 (footnote [C]), derived from Menu (1993).

In the test, an independent data set consisting of results from 100 (experimental) fields was used. Most of these were part of trials on N-supply. Those receiving the recommended supply, were described by Smit and Struik (1995a). Additional information is given in Table 1 (footnote [A]).

The prediction error, the absolute difference between observed and predicted values, was calculated for every variable and every field, expressed in units and in percentages of the observed values, and averaged over all fields. In addition, linear regression analysis was applied to test how well the predicted values matched the observed ones. The explained variance (R^2) was used as a measure.

The applied version of PIEteR included effects of N-level as well, described by Smit *et al.* (1995). Plant density and N-effects on yield and quality were assumed to be additional, i.e. interaction between plant density and N-level was thought to be absent. This hypothesis was tested on 96 fields of the independent data set. The relationships between yield and quality on the one hand and available nitrogen per ha and per plant, respectively, on the other hand were derived and compared by applying the method of linear regression analysis; the resulting correlation coefficients were statistically tested. The critical value for the correlation coefficient was 0.17 for 96 observations ($P = 0.05$).

Table 1. Test results of PIEteR over 100 fields, with and without correction for plant density.

Test [A]	Par. [B]	Results		Mean prediction error		Expl. variance
		Observed	Simulated	(kg.m^{-2}, %, mmol, kfl.ha^{-1})	(%)	(R^2, %)
1	Root	6.13	6.30	0.78	14.9	40.4
2	Root	6.13	6.26	0.70	12.2	58.3
3	Root	6.13	6.27	0.67	11.5	60.4
1	Sugar	1.04	1.07	0.12	13.9	45.7
2	Sugar	1.04	1.06	0.11	12.0	59.5
3	Sugar	1.04	1.06	0.11	10.9	64.7
1	S.cont	16.9	16.9	0.7	4.0	4.0
2	S.cont	16.9	17.0	0.6	3.3	24.4
3	S.cont	16.9	16.9	0.5	3.1	31.6
1	K+Na	29.51	34.19	6.05	21.7	42.1
2	K+Na	29.51	33.98	5.92	21.0	46.1
3	K+Na	29.51	33.15	5.19	18.3	50.7
1	αN	12.49	13.76	4.76	48.0	0.1
2	αN	12.49	13.39	3.30	29.4	35.4
3	αN	12.49	12.82	3.13	26.8	40.0
1	Extr	89.5	88.2	2.4	2.7	26.7
2	Extr	89.5	88.1	2.5	2.8	35.2
3	Extr	89.5	88.4	2.1	2.5	45.1
1	Pay [C]	7.81	7.99	0.94	13.6	40.5
2	Pay [C]	7.81	7.96	0.85	11.8	55.0
3	Pay [C]	7.81	7.94	0.76	10.3	63.9

[A] 1 = without corrections for plant density and N-availability
2 = with corrections for N-availability, but not for plant density
3 = with corrections for both N-availability and plant density

Additional information over 100 fields:

- Average sowing date: day 98 (8 April)
- Average simulated GPD: day 175 (24 June)
- Average plant density (spring): 7.6 plants.m^{-2}
- Average amount of N in soil layer 0-60 cm (February): 51 kg.ha^{-1}
- Average level of N-fertilization: 127 kg.ha^{-1}.

B	"Root"	= fresh root yield	[$kg.m^{-2}$]
	"Sugar"	= sugar yield	[$kg.m^{-2}$]
	"S.cont"	= calculated sugar content	[%]
	"K+Na"	= (K + Na) content	[mmol.(100 g sugar)$^{-1}$]
	"αN"	= α-amino-N-content	[mmol.(100 g sugar)$^{-1}$]
	"Extr"	= extractability index (Van Geijn *et al.*)	[-]
	"Pay"	= operating receipts	[kfl (=1000 Dutch guilders)]

C Sales system:
0.115 kfl (1 kfl = 1000 Dutch guilders) per net ton of sugar beets, corrected with 9% per percent sugar content above or under 16% and with 0.9% per point extractability index above or under 85; penalties for dirt tare were not included in our calculations. This system was used in 1993 by Suiker Unie, one of the sugar beet processing companies in the Netherlands (Menu, 1993).

Results

1. Results of modelling

Sugar content and extractability

Figure 1 shows the general course of (K + Na) and α-amino-N contents and extractability over time, in days after GPD, on clay soils in the province of Zeeland. Data of the period after 120 days after GPD (in many years close to November 1st) were scarce. The (K + Na) and α-amino-N contents were assumed to remain constant from that day onwards at a value of 34.2 and 12.6 mmol.(100 g sugar)$^{-1}$, respectively. Consequently, the simulated extractability index (according to equation 1) was constant from that day onwards at a value of 88.3. The functions for different soil types and regions differed in shape and/or final level.

Plant density effects

Figures 2A-B show the relationships between yield and quality parameters on the one hand and plant density on the other, both from our own analysis and from Märländer (1990).

In our own analysis fresh root and sugar yields had maxima at 9.4 and 9.7 plants.m^{-2}, respectively (Figure 2A). Sugar content increased with increasing plant density, but decreased slowly beyond 11.0 plants.m^{-2} (Figure 2B). The relative sugar content was higher than 100 when plant density was above 8.1 plants.m^{-2}. Both (K + Na) and α-amino-N contents decreased with increasing plant density (Figure 2B). In our analysis the decrease was almost linear and stronger for α-amino-N than for (K + Na). Märländer's curves for (K + Na) and α-amino-N contents had a more quadratic shape than ours and a lower general level.

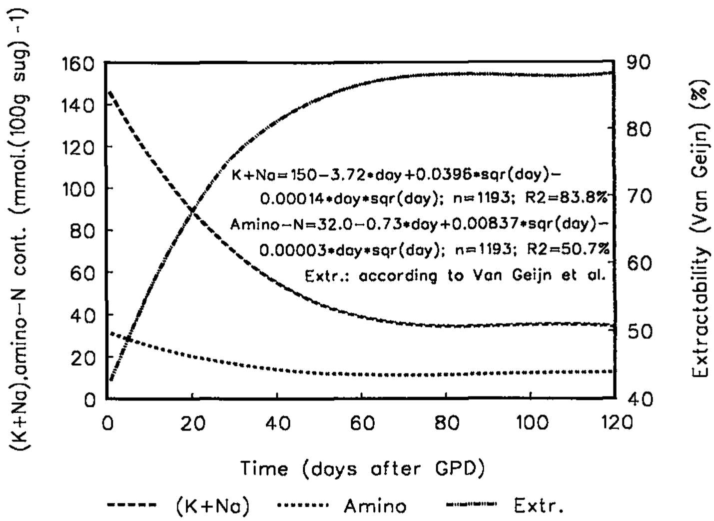


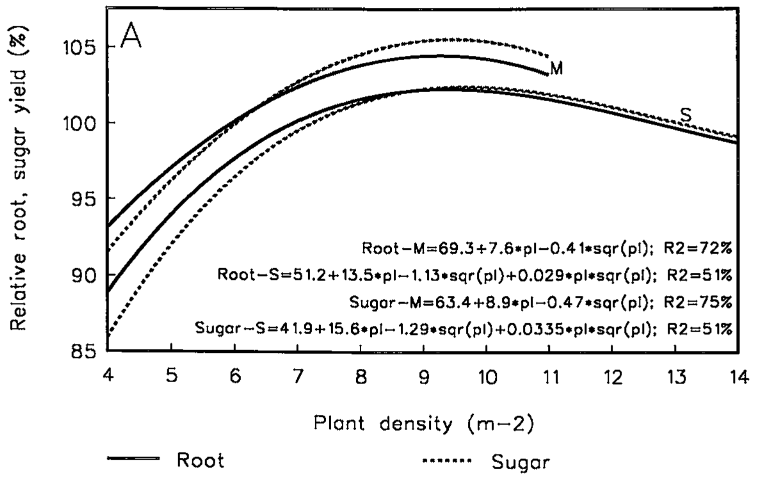
Figure 1. General course of (K + Na) and α-amino-N contents (both in mmol.(100 g sugar)$^{-1}$) and extractability (Extr.) during the growing season (clay soils in the province of Zeeland).

2. *Results of tests*

The simulation results with and without correction for plant density are given in Table 1. The explained variance of all parameters in the model increased through plant density correction and the prediction error decreased.

In all cases the quality parameter was overestimated at low values and underestimated at high values. Figure 3 shows that the integrating parameter, operating receipts, was overestimated in about 55% of the predictions. The predicted course of the quality parameters during the season was in some cases not very accurate (Smit *et al.*, 1995), but the extractability index at final harvest had a mean relative prediction error of only 2.5%.

The correlation test showed that all parameters had a correlation coefficient much greater than the critical value ranging from 0.81 to 0.96.



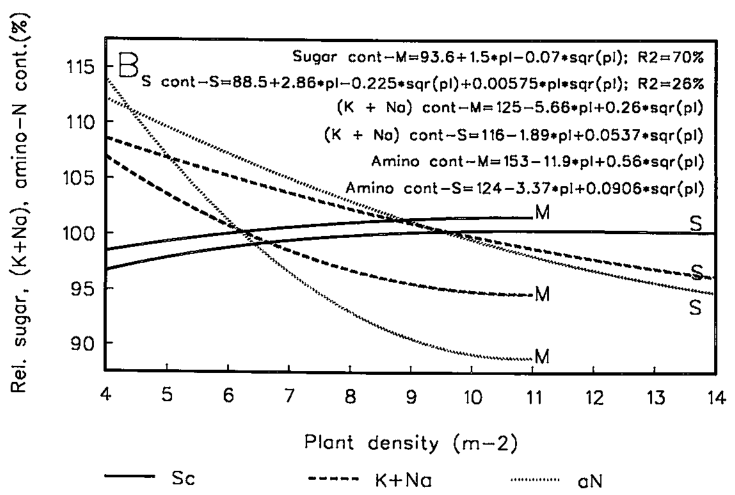


Figure 2. Relative root and sugar yields, and sugar, (K + Na) and α-amino-N contents versus plant density (pl), from our own analysis (S) and from Märländer (M); 100% = means of experiment. A: Root and sugar yields; B: Sugar content and (K + Na) and α-amino-N contents.

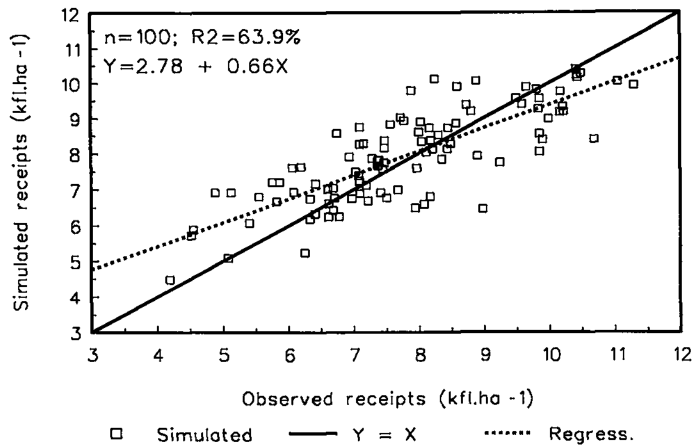


Figure 3. Simulated versus observed operating receipts (kfl.ha^{-1})

Discussion

1 Results of modelling

Extractability

The curves in Figure 1 only give a rough picture of the course of quality parameters over time. In a German experiment in 1984, (K + Na) and α-amino-N contents decreased until final harvest, which took place in the first weeks of November (Bürcky and Winner, 1986). Specific soil and weather conditions determine the actual course of both contents to a large extent (Oltmann *et al.*, 1984), which have not been taken into account in the model, so far. The general effect of plant density on the extractability index will be more or less the same as the effect on sugar content, the latter being the most determining factor in its calculation.

Plant density effects

The comparison with Märländer's analysis showed mainly differences in level, not in optimal plant density; Märländer's relative values for yield were higher and for impurity contents lower, so that both quantity and internal quality had a higher level than in our analysis. Two factors caused this difference. Firstly, Märländer's plant density range was less wide than ours. Secondly, Märländer did his experiments with only one variety and he applied thinning-by-hand twice in the early growing season. Both measures must have had a favourable effect on both yield level and uniformity (resulting in higher quality and higher values of explained variance) in comparison with our data. In experiments of Van der Beek (1974) drilling to-a-stand led to a root yield reduction of 3% on average, compared to thinning of closely drilled plants. The sugar content was not influenced, so that sugar yield was reduced to the same extent as root yield, which is also illustrated in Figure 2A. According to Bornscheuer (1981) extractable sugar yields in thinned fields were up to 7% higher than in fields with the same plant density without thinning; for plant densities near the optimum, 8 plants.m^{-2}, the differences were very small. Since our own data were based on a more realistic situation (different varieties, drilling to-a-stand) we decided to apply our own functions, although Märländer's level of explained variance was higher.

Smit (1993) applied the general relationship between individual plant yield and plant density which had been derived by Bleasdale (1966), to sugar beet. The resulting equation was based on plant densities not exceeding 10 plants.m^{-2} and showed that with increasing plant density individual root weight would decrease to give near constant yield per unit of area. In our analysis there was a maximum sugar yield at 9.7 plants.m^{-2}. The decrease beyond this plant density cannot be described by Smit's equation.

Bornscheuer (1981) reported that fresh root yield and sugar content decreased by 6 and 3% respectively, when plant density decreased from 7.5 to 5.5 plants.m^{-2}. From Figure 2A it can be derived that in our analysis the decreases were 5 and 1%, respectively. Kästner (1984) reported that a deviation of 1 - 1.5 plants.m^{-2} from the optimum plant density (8 - 10 plants.m^{-2}) did not necessarily lead to yield losses. However, a crop with fewer than 6 plants.m^{-2} would in general show a significant loss. A sugar beet plant is able to utilize 1500 cm^2 at maximum, indicating a minimum plant density without yield loss of 6.7 plants.m^{-2}.

O'Connor (1984) found increasing sugar contents and extractability indices and decreasing (K + Na) and α-amino-N contents with increasing plant density over the range 5 - 10 plants.m^{-2}. The decrease was stronger for α-amino-N than for (K + Na).

According to Milford (1976) the number of cambium rings in the root is not influenced by plant density, probably because these are formed at a very early stage. The number of rings which fully develop, ring size, number of cells per ring and cell size decrease and their sugar storage capacity, which is only slightly related to cell size, increases with increasing plant density. As a result sugar concentration increases.

Soon after emergence, growers count the number of plants in the field by random sampling in order to evaluate the success of emergence and the possible need to resow. Smit (1989) developed a model to support decisions in this respect. The counted or estimated number of plants in spring served as an input parameter for PIEteR. Plant distribution was not accounted for; when strong variation occurs and part of the field has very low plant densities (fewer than 6 plants.m^{-2}), it may be helpful to divide the field into more or less uniform parts.

It is not easy for the sugar beet grower to reach the optimal plant density. In the first place field emergence, which is in general 80% or more (Jorritsma, 1985), may be different for different years or fields. In the second place the weather conditions after sowing, especially occurrence of severe drought stress, water surplus or frost, can reduce field emergence remarkably. In the third place damage by diseases and plague animals may occur, although chemical protection of the seeds may reduce this risk to a large extent.

High plant densities have some additional effects, which have not been analysed in this paper but might be relevant for a decision support system. Märländer and Bräutigam (1994) reported an increasing weed suppressing effect with increasing plant density. Schäufele (1992) suggested that chemical weed control in sugar beet should be related to damage thresholds as commonly practised in cereals. The level of such thresholds would probably be influenced by both plant density and plant distribution, which are both determined by field emergence (Van der Beek, 1993a).

Amounts of dirt tare tend to increase with plant density. The combination of a large number of beets and a smaller size tends to result in more tare than the combination of a smaller number and a larger size, which is due to a less favourable ratio between surface area/volume of smaller beets and a decrease of the part of the beet which grows above ground (Bornscheuer, 1981). Van der Beek and Jager (1979) found a strong increase of total tare beyond 9 plants.m^{-2}. Another disadvantage of smaller beets is that they have a greater risk to get lost during harvest (CPRO-DLO, 1993).

In The Netherlands it is advised to aim at 8 - 9 plants.m^{-2}, taking into account the influence of plant density on root and sugar yields, internal quality and tare (Jorritsma, 1985; Van der Beek, 1992a,b). Under normal conditions the optimal amount of seed is 10 - 11 seeds.m^{-2}, based on an average field emergence of 84%.

Plant density may become supra-optimal under very favourable conditions for emergence and plant establishment, but correction can occur to a certain extent by self-singling (Neeb and Winner, 1968). This is a normal process in a sugar beet crop during the whole season, resulting from competition for water, nutrients and light (Märländer, 1990). According to Van der Beek and Jager (1979) the loss of plants during the season increases progressively with plant density. Aiming at a supra-optimal plant density as a kind of risk reduction strategy must not be stimulated because of inefficiency losses through competition and the costs of extra planting material.

2. *Results of tests*

The prediction of root and sugar yields and of sugar content improved by including plant density corrections. The mean prediction error of the extractability index was much smaller than those of the (K + Na) and α-amino-N contents, although the first was calculated from the latter two (Table 1). A mean relative prediction error of about 3% for sugar content and extractability index is acceptable, but coefficients of determination of 32% and 45% respectively are low. A good prediction of both parameters is difficult due to the complexity of the relationships between quality and nitrogen supply (Smit *et al.*, 1995). The explained variances of sugar and root yields were higher than for their ratio (calculated sugar content).

The model could best be used for 'normal' situations, since low values of (K + Na) and α-amino-N contents and high values of extractability and operating receipts were predicted best. The prediction of the extractability index during the season, especially from the start of sugar beet processing campaign onwards (about day 270), was satisfactory.

The correlation test showed the absence of interaction between the factors plant density and nitrogen supply. According to Van der Beek (1993b) there is no interaction between plant density and variety, except for some varieties in case of dirt tare.

Both the quality and plant density modules improved the ability of PIEteR for accurate decision support.

Acknowledgements

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References

Beek, van der, M.A., 1974. Resultaten van proeven met rijenafstanden en dunmethoden bij suikerbieten in 1972 en 1973. *Bedrijfsontwikkeling* **5**, 11, 979-984, 1974.

Beek, van der, M.A., 1992a. Aandachtspunten bij de zaaibedbereiding en het zaaien. *CSM Informatie* **465**, 12-13.

Beek, van der, M.A., 1992b. Teeltfactoren in relatie tot de interne kwaliteit, wat is wel en niet te beïnvloeden. Artikelen Suikerbieten Informatiedagen. Bergen op Zoom, DLV/IRS: 1-10.

Beek, van der, M.A., 1993a. Beschouwingen over enkele teeltaspecten bij suikerbieten. Bergen op Zoom, IRS, Interne mededeling nr. 139, 24 pp.

Beek, van der, M.A., 1993b. Onderzoek naar de gebruikswaarde van suikerbieterassen. Jaarverslag 1992. Bergen op Zoom, The Netherlands, Instituut voor Rationele Suikerproduktie: 8-9.

Beek, van der, M.A. & A.W.M. Huijbregts, 1986. Internal quality aspects of sugar beet. Proceedings No. 252 of The Fertiliser Society, London, 11 December 1986. London, Greenhill House, 20 pp.

Beek, van der, M.A. & J. Jager, 1979. Onderzoek naar de invloed van het plantaantal in het voorjaar op de opbrengst van suikerbieten bij zaaien op eindafstand. *Bedrijfsontwikkeling* **10**, 2, 177-183.

Bleasdale, J.K.A., 1966. Plant growth and crop yield. *Annals of Applied Biology* **57**, 173-182.

Bornscheuer, E., 1981. Wieviel Standraum benötigt die Zuckerrübe? *DLG-Mitteilungen* **96**, 4, 201-203.

Bürcky, K. & C. Winner, 1986. Einfluß der Bestandesdichte auf Ertrag und Qualität der Zuckerrübe bei unterschiedlichem Erntetermin. *Journal of Agronomy and Crop Science* **157**, 4, 264-272.

O'Connor, L.J., 1983. Influence of nitrogen fertiliser, plant density, row width and their interactions on sugar-beet yield and quality. *Irish Journal of Agricultural Research* **22**, 189-202.

O'Connor, L.J., 1984. The influence of level of topping, N fertilization, plant density and row width on sugar beet yield and quality, and crown tissue production. Proceedings IIRB-congress, Brussels, Belgium, 15-16 February 1984. Brussels, IIRB: 383-403.

CPRO-DLO, 1993. 69e Beschrijvende rassenlijst voor landbouwgewassen 1994. Wageningen, The Netherlands, 342 pp.

Geijn, van, N.J., L.C. Giljam & L.H. de Nie, 1983. α-amino-nitrogen in sugar processing. Proceedings IIRB-symposium "Nitrogen and sugar-beet", Brussels, Belgium, 16-17 February 1983. Brussels, IIRB: 13-24.

Jorritsma, J., 1985. De teelt van suikerbieten. Zutphen, Terra. Groene Reeks, 286 pp.

Kästner, B., 1984. Zusammenhänge zwischen Feldaufgang, Kornabstand, Pflanzenanzahl und Pflanzenverteilung von Zuckerrüben sowie Schlußfolgerungen für die Standraumzumessung. *Archiv für Acker- und Pflanzenbau und Bodenkunde* **28**, 9, 561-568.

Last, P.J. & A.P. Draycott, 1977. Relationships between clarified beet juice purity and easily-measured impurities. *International Sugar Journal* **79**, 183-185.

Märländer, B., 1990. Einfluß der Bestandesdichte auf Ertrags- und Qualitätskriterien sowie über mögliche Ursachen der Konkurrenz in Zuckerrübenbestanden. *Journal of Agronomy and Crop Science* **164**, 2, 120-130.

Märländer, B. & H. Bräutigam, 1994. Bestandesdichte von Zuckerrüben und Intensität der Verunkrautung - erster Ansatz Integrierter Unkrautregulierung. *Gesunde Pflanzen* **26**, 4, 117-122.

Menu, W.J.L., 1993. Wijziging kwaliteitsbetaling suikerbieten. *Maandblad Suiker Unie* **27**, 11, 6-7.

Milford, G.F.J., 1976. Sugar concentration in sugar beet: varietal differences and the effects of soil type and planting density on the size of the root cells. *Annals of Applied Biology* **83**, 251-257.

Neeb, O. & C. Winner, 1968. Zur Problematik des Zuckerrübenanbaues ohne Vereinzelung. *Zucker* **21**, 445-450, 463-468.

Oltmann, W., M. Burba & G. Bolz, 1984. Die Qualität der Zuckerrübe. Bedeutung, Beurteilungskriterien und züchterische Maßnahmen zu ihrer Verbesserung. Berlin/Hamburg, Verlag Paul Parey. Advances in Plant Breeding. Supplement **12** to *Journal of Plant Breeding*, 159 pp.

SAS Institute, 1988. SAS Language Guide. Release 6.03 Edition. Cary, USA, 1042 pp.

Schäufele, W.R., 1992. Unkrautbekämpfung in Zuckerrüben nach Schadensschwellen. Proceedings IIRB-congress, Brussels, Belgium, 12-13 February 1992. Brussels, IIRB: 353-359.

Smit, A.L., 1989. Overzaaien van suikerbieten. Lelystad, The Netherlands, PAGV-verslag nr. 91, 78 pp.

Smit, A.L., 1993. The influence of sowing date and plant density on the decision to resow sugar beet. *Field Crops Research* **34**, 159-173.

Smit, A.B. & P.C. Struik, 1995a. The first step towards a decision support system for sugar beet growing: selection of a basic model. *Journal of Agronomy and Crop Science* **175**, 213-220.

Smit, A.B. & P.C. Struik, 1995b. PIEteR: a field-specific production model for sugar beet growing. *Journal of Agronomy and Crop Science* **175**, 335-348.

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1995. Nitrogen effects in sugar beet growing. A module for decision support. *Netherlands Journal of Agricultural Science* **43**, 4, 391-408.

CHAPTER 6

Critical plant densities for resowing of sugar beet

A.B. Smit, P.C. Struik, J.H. van Niejenhuis and J.A. Renkema

Abstract
In case of poor crop establishment of sugar beet, the grower may consider to resow. In his considerations, the differences between the actual and the optimal plant densities and their effects on yield and quality must play an important role. A module to describe these effects is presented. The later in the growing season the decision has to be taken, the lower the plant densities for which resowing is profitable.

Keywords: sugar beet, *Beta vulgaris*, decision support, plant density, sowing date, resowing

Introduction

The production model PIEteR (PIEteR means: 'Production model for sugar beet, including Interactions between Environment and growing decisions, and their influence on the quantitative, qualitative and financial Result') has been developed as a basis for a decision support system in sugar beet (*Beta vulgaris* L.) growing in The Netherlands. It predicts root and sugar yields, from which sugar content is calculated, (K + Na) and α-amino-N contents, from which the extractability index is calculated, and the operating receipts (defined as the amount of money that the farmer receives after delivering his beets, corrected for internal quality: sugar content and extractability index according to Van Geijn *et al.* (1983)), which are calculated from the yield and quality parameters (Smit and Struik, 1995; Smit *et al.*, 1995). The simulated rates of crop growth until canopy closure and of root and sugar production after this point in crop growth are corrected for suboptimal soil moisture contents. PIEteR also accounts for plant density and nitrogen effects.

When emergence is impeded, the crop stand will be incomplete and irregular, resulting in reduced light interception and, consequently, lower root and sugar yields and probably lower quality. Resowing could lead to a better stand, but two types of costs have to be accounted for: the costs of extra seed, labour, etc., and the costs of production losses resulting from a later start. A decision on resowing must be based on a clear insight into the effects of plant density, but such effects change with sowing date, as shown by Westerdijk and Zwanepol (1994).

This paper analyses the decision on resowing, making use of PIEteR.

Materials and methods

For different combinations of sowing and resowing dates in a field with clay soil in Wageningen, The Netherlands, PIEteR simulated final root and sugar yields, applying 'average' weather files as described in Smit *et al.* (1996). We assumed that resowing would result in a plant density of 8 plants.m^{-2}, and costs of resowing would be 0.40 kfl.ha^{-1} (costs of seed and contract sowing in the area of Wageningen (Roeterdink *et al.*, 1993)). The expected operating receipts from the first sowing date with different plant densities and from the resowing date with 8 plants.m^{-2} were calculated and hence the maximum plant density for which resowing would be profitable:

$$oper.rec._2 - costs > oper.rec._1 \tag{1}$$

in which

oper.rec.$_2$	=	Operating receipts at harvest after resowing	[kfl.ha^{-1}]
costs	=	Costs of resowing	[kfl.ha^{-1}]
oper.rec.$_1$	=	Operating receipts at harvest without resowing	[kfl.ha^{-1}].

The operating receipts were calculated as described in earlier papers (Smit and Struik, 1995), but the relatively small corrections for extractability index were not included. The plant density effects included have been described by Smit *et al.* (1995). For different combinations of sowing and resowing dates, we calculated the differences between the operating receipts of a successfully resown crop (8 plants.m^{-2}) and those of an original crop with different lower plant densities. For every combination, a maximum plant density for the original crop ('critical plant density') was found for which the difference equalled the resowing costs. For higher plant densities, resowing would not be profitable. The resulting critical plant densities for the different combinations were compared with the values given in Westerdijk and Zwanepol (1994). Their calculations were based on sugar yield predictions and a fixed sugar price.

Results

Table 1 gives the critical plant densities for resowing with different combinations of sowing and resowing dates. Figure 1 gives the assessment of critical plant densities for a specific sowing date (12 April or day 102) with different resowing dates. Operating receipts after correcting for resowing costs with successful resowing on day 118 (28 April) would be 7.31 kfl.ha^{-1}. An original crop would only do better when its plant density would be greater than

Table 1 Critical plant densities for resowing with different combinations of sowing and resowing dates, calculated for a field on a clay soil in Wageningen, The Netherlands, applying 'average' weather files (cf. Smit *et al.*, 1996).

Sowing date[1]		Critical plant density ($plants.m^{-2}$) with resowing date[1]:												
		April				May								June
		16	20	24	28	2	6	10	14	18	22	26	30	3
March	31	6.0	5.8	5.4	5.3	4.8	4.5							
April	4	6.2	6.0	5.6	5.4	5.0	4.6	4.3						
	8	6.4	6.1	5.8	5.6	5.1	4.8	4.5	4.0					
	12		6.6	6.1	6.0	5.4	5.1	4.7	4.3	3.9				
	16			6.3	6.1	5.6	5.2	4.9	4.4	3.9				
	20				6.3	5.8	5.4	5.0	4.5	4.1	3.7			
	24					6.1	5.7	5.3	4.8	4.3	4.0			
	28						5.9	5.5	4.9	4.5	4.1	3.7		
May	2							6.0	5.4	4.8	4.5	4.0		
	6								5.8	5.2	4.8	4.3		
	10									5.5	5.1	4.6	4.1	
	14										5.6	5.1	4.5	4.0
	18											5.6	5.0	4.4
	22												5.4	4.8
	26													5.2

[1] Predictions with densities below 3.5 $plants.m^{-2}$ were deleted from the table since they are unrealistic for certain varieties.

6.0 $plants.m^{-2}$, being the critical plant density for sowing on 12 April and resowing on 28 April. The shaded area gives the loss in operating receipts compared to a crop with 8 $plant.m^{-2}$ that emerged successfully after sowing on the initial sowing date. This loss increased when the event that caused the necessity of resowing, occurred later.

The respective densities in Table 1 increase in each column from top to bottom and decrease in each row from left to right. The critical plant densities also decrease over each diagonal line from the left top to the right bottom, varying from 3.7 $plants.m^{-2}$ with sowing date 28 April and resowing date 26 May to 6.6 $plants.m^{-2}$ with dates 12 April and 20 April, respectively.

Model calculations showed that with delayed sowing date, root and sugar yields both decreased, but sugar yield more than root yield (Figure 2A); sugar content decreased and tare content increased (Figure 2B). Both figures were drawn for a plant density of 8 $plants.m^{-2}$.

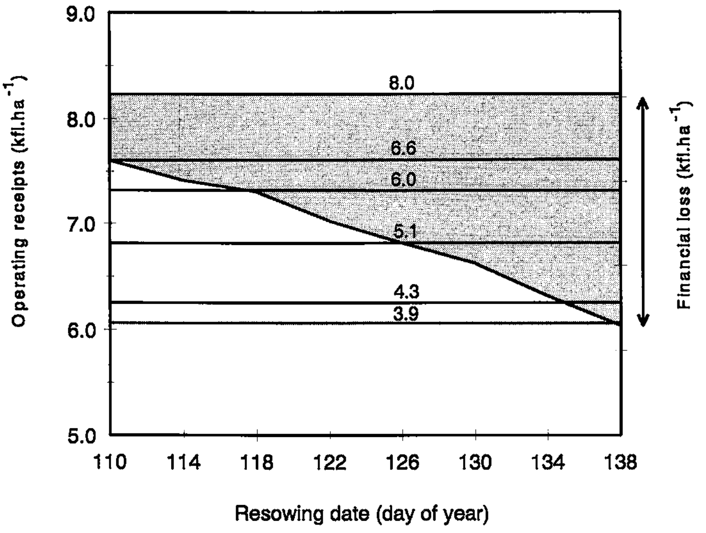


Figure 1. Gross operating receipts of a sugar beet crop, sown on 12 April, with different plant densities, and net operating receipts (corrected for resowing costs) with different resowing dates. (horizontal lines: Gross operating receipts of the initial crop; numbers give the respective plant density per m^2; diagonal line: Net operating receipts of the resown crop).

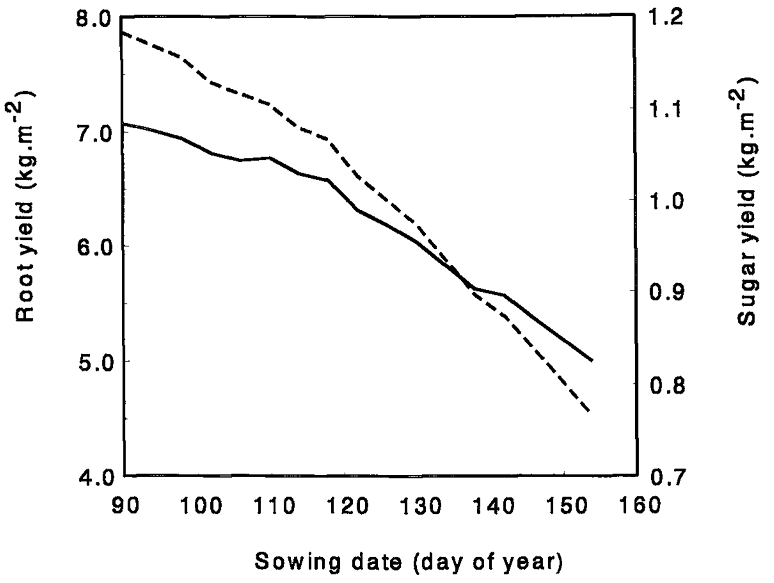
Discussion

Going from top to bottom in Table 1, the period between sowing and resowing dates and therefore the production of the initial crop lost through resowing, decrease. The shorter the period between sowing and the moment that the grower can decide on resowing, the higher the critical plant density. This effect is also found in the rows, going from right to left.

The later the crop is sown, the lower the critical plant density in general will be; a delay of sowing date with a certain number of days has an increasing effect on the rate of growth of the crop and on the so-called 'growth point date' (GPD), which nearly coincides with closed canopy (Smit and Struik, 1995). Consequently, there is an increasing loss of root and sugar yields with delayed sowing dates.

The information in Table 1 agrees to a certain extent with the data of Westerdijk and Zwanepol (1994), especially in the early phase of the sowing season. Their critical values are

A



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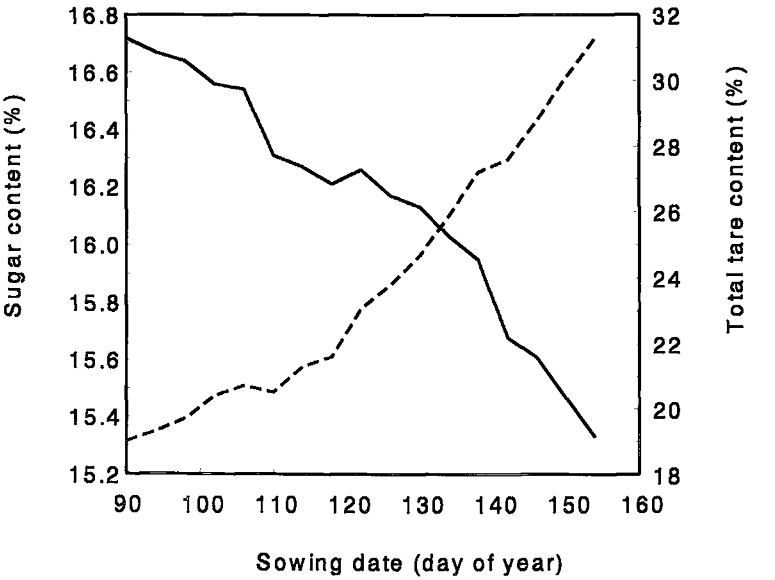

Figure 2 Results of simulations by PIEteR for a field in Wageningen with average weather files. A: Root and sugar yields vs. sowing date. (___ : root yield; - - : sugar yield); B: Sugar and total tare contents vs. sowing date. (___ : sugar content; - - : total tare content)

lower for sowing and resowing dates after 24 April and 18 May, respectively. In their table, values of less than 3.5 plants.m^{-2} are found; crops with such plant densities may give great problems during mechanical harvest, depending on variety (H.C. Antonissen, CSM Suiker, pers. comm., 1996; M.A. van der Beek, pers. comm., 1996).

The plant densities in Table 1 are only valid when emergence after resowing is successful. The risk of drought stress in the seedbed increases with time, which is not taken into account in our analysis, but the sugar beet grower should consider the soil moisture condition of the field and the weather forecasts before deciding to resow. When weather conditions lead to a delay in resowing of a week, the effect on the critical plant density can be found in Table 1.

PIEteR simulated root yields and calculated sugar content as the ratio between sugar and root yields. Since both root yield and sugar content are taken into account in the calculation of the operating receipts, PIEteR gives a more refined approach than Westerdijk and Zwanepol. Figures 2A-B show that changes in sugar content take place with a delay in sowing. However, in practice sugar content is not affected by a delay of sowing date from 31 March to 20 April; after this date the expected sugar content indeed decreases (M.A. van der Beek, pers. comm., 1996).

The conditions leading to a poor crop establishment may also result into a lack of growth vigour, making resowing even more profitable than given in Table 1; when the grower considers to resow, he has to be reasonably sure that the current conditions will lead to a favourable crop stand. Unfavourable conditions as pests must therefore be corrected for to make the calculations valid.

Sowing later leads in general to higher tare contents because of smaller beets (Figure 2B). However, the simulated increase for a clay soil is higher than observed in practice (P. Wilting, Dutch Sugar Beet Research Institute (IRS), pers. comm., 1996). The penalties for tare were not included in the calculations of the operating receipts. However, resowing commonly leads to a more regular crop stand, resulting in lower tare contents (Westerdijk and Zwanepol, 1994).

Acknowledgements

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References

Geijn, van, N.J., L.C. Giljam & L.H. de Nie, 1983. α-Amino-nitrogen in sugar processing. In: Proceedings of the IIRB-symposium "Nitrogen and sugarbeet", Brussels, Belgium, 16-17 February 1983. Brussels, IIRB: 13-25.

Roeterdink, H.W., J.J. Haaksma & S. Zwanepol, 1993. Kwantitatieve informatie voor de akkerbouw en de groenteteelt in de vollegrond. Bedrijfssynthese 1993 - 1994. Lelystad, IKC-AGV and PAGV, Publikatie nr. 68, 212 pp.

Smit, A.B. & P.C. Struik, 1995. PIEteR: a field-specific production model for sugar beet growing. *Journal of Agronomy and Crop Science* **175**, 335-348.

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1995. Modelling the influence of plant density on yield, sugar content and extractability of sugar beet. In: Proceedings of the 58th IIRB-congress, 19-22 June 1995, France. Brussels, IIRB: 413-424.

Smit, A.B., P.C. Struik & J.H. Van Niejenhuis, 1996. Prediction of various effects of harvest date in sugar beet growing. *Journal of Agricultural Engineering Research* (submitted).

Westerdijk, C.E. & S. Zwanepol (eds.), 1994. Teelt van suikerbieten. PAGV Teelthandleiding nr. 64. Bergen op Zoom, IRS, and Lelystad, PAGV, 121 pp.

CHAPTER 7

Nitrogen effects in sugar beet growing: a module for decision support

A.B. Smit, P.C. Struik & J.H. van Niejenhuis

Abstract

PIEteR is a field-specific production model for sugar beet growing in The Netherlands, developed as a basis for decision support, for example in nitrogen fertilization. Root and sugar yields, sugar content, (K + Na) and α-amino-N contents, extractability index, operating receipts (a measure for financial returns) and residual nitrogen in leaves were modelled as functions of nitrogen availability, defined as (N-fertilizer rate + $N_{min,\ 0\text{-}60\ cm}$ (soil, February)), and included in PIEteR as a so-called 'N-module'.

Analysis of experimental data showed that root and sugar yield were optimal at 240 and 200 kg $N.ha^{-1}$, respectively. Sugar content and extractability index decreased, and (K + Na) and α-amino-N contents and fresh leaf yield increased with increasing N-availability. The operating receipts were optimal with 180 $kg.ha^{-1}$, or with a nitrogen fertilizer rate of 130 $kg.ha^{-1}$, assuming an N_{min}-amount in soil in February of 50 $kg.ha^{-1}$. The results of the analysis were the basis for the functions in the N-module.

In an independent test on data of 100 fields, the prediction errors for root and sugar yields and financial result decreased by about 2% and the explained variances increased by about 15% by including the N-module.

Keywords: decision support, nitrogen fertilization, simulation model, sugar beet, *Beta vulgaris* L.

Introduction

The production model PIEteR [1] has been developed as a basis for a decision support system in sugar beet (*Beta vulgaris* L.) growing in The Netherlands. It predicts root and sugar yields, from which sugar content is calculated, (K + Na) and α-amino-N contents, from

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[1] PIEteR means: '**P**roduction model for sugar beet, including **I**nteractions between **E**nvironment and growing decisions, and their influence on the quantitative, qualitative and financial **R**esult'.

which the extractability index is calculated, and the operating receipts [2] which are calculated from the relevant yield and quality parameters (Smit and Struik, 1995; Smit *et al.*, 1995).

Two of the main decisions in sugar beet growing concern plant density and N-fertilization rate. In another paper we focused on the effects of plant density (Smit *et al.*, 1995). In that paper we hypothesised and proved absence of interaction between nitrogen availability and plant density. In the current paper N-fertilization is discussed, which has major effects on both yield and internal quality (Oltmann *et al.*, 1984; Van der Beek and Huijbregts, 1986). When the element N is short in supply, yield may be drastically reduced (Draycott, 1993). Nitrogen fertilizer usually depresses sugar content and juice purity (Van Burg *et al.*, 1983). With increasing N-rates more α-amino acids are produced and more Na^+- and (in most soils) K^+-ions are taken up by the roots; these ions accompany the accumulation of NO_3^--ions, keeping the anion-cation ratio balanced (Van Egmond, 1975). α-Amino acids and Na^+- and K^+-ions all reduce sugar beet quality, meaning that the percentage of sugar that can be extracted, decreases. To neutralize the acidifying α-amino-N compounds, NaOH is added; Na^+- and K^+-ions associate with sucrose-ions to non-extractable compounds (Jorritsma, 1985).

Chances that part of the minerals available in the root zone is lost during or after the growing season, are greater for N than for other elements such as P and K. Losses result mainly from leaching, denitrification and ammonia emission, partly leading to contamination of drinking water and air, respectively (Draycott, 1993; Olsson and Bramstorp, 1994). In our analysis of effects of N-fertilization on environment in this paper we focus on the amount of N_{min} which is found in the soil profile 0-60 cm and on the amount of (mainly organic) N in the crop residues immediately after harvest. Neeteson and Ehlert (1989) observed mean amounts of about 30 $kg.ha^{-1}$ and 100 $kg.ha^{-1}$ respectively with normal N-levels; even with very high N-levels only 40 $kg.ha^{-1}$ was found in the soil profile and 150 $kg.ha^{-1}$ in the crop residues (P. Wilting, IRS, pers. comm., 1995).

The aim of our study was to produce an N-module which would be a simple and solid basis for decision support in sugar beet growing, not to fully understand and describe the N-balance in sugar beet growing. After a preliminary analysis of literature and data we decided to define 'nitrogen availability' and to describe the effects of mineral nitrogen fertilization on yield, quality, operating receipts and remaining N in crop residues, not taking into account the dynamics of processes leading to extra N available (mineralization) or N-losses (leaching, denitrification). Organic N fertilization was not considered in this study.

[2] A measure for financial returns; more information is given in footnote 3 of Table 1.

Materials and methods

Relevant equations

In this paper, the extractability index is calculated according to Van Geijn *et al.* (1983):

$$Extr = 100 - (0.342 * (K + Na) + 0.513 * (\alpha N - 17)) \tag{1}$$

in which

Extr	=	Extractability index of sugar beet (according to Van Geijn *et al.*)	[-]
K	=	K content	[mmol.(100 g sugar)$^{-1}$]
Na	=	Na content	[mmol.(100 g sugar)$^{-1}$]
αN	=	α-amino-N content	[mmol.(100 g sugar)$^{-1}$]
100	=	Value of Extr if impurities are absent	[-]
0.342	=	The amount of sugar per unit K+Na lost in molasses [3]	[g.(mmol K+Na)$^{-1}$]
0.513	=	The amount of sugar per unit α-amino-N lost in molasses [4]	[g.(mmol α-amino-N)$^{-1}$]

The minimum value of α-amino-N content in the equation is 17 mmol.(100 g sugar)$^{-1}$. Note that impurities are expressed on the basis of 100 g sugar and not on the basis of fresh weight of the beet.

Nitrogen availability is defined as:

$$N\text{-}available = N_{min,0-60\,cm} + N\text{-}fertilization \tag{2}$$

in which

N-available	=	Amount of mineral N (NH_4^+ + NO_3^-), which is available after fertilization	[kg.ha^{-1}]
$N_{min,\ 0\text{-}60\ cm}$	=	Amount of mineral N, assessed in February in the soil layer 0-60 cm	[kg.ha^{-1}]
N-fertilization	=	Amount of N, applied in February-April as mineral fertilizer	[kg.ha^{-1}]

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[3] 1 mmol of K+Na is accompanied by 1 mmol (or 0.342 g) of sugar.

[4] 1 mmol of α-amino-N (above the limit of 17 mmol.(100 g sugar)$^{-1}$) is accompanied by 1.5 mmol sugar.

The recommended N-fertilization rate for sugar beet crops on Dutch clay, loess and sandy soils is given in Equation 3, aiming for the financial optimum (but not including costs of nitrogen fertilizer itself; Draycott, 1993; Neeteson and Smilde, 1983):

$$N\text{-}fertilization = 220 - 1.7 * N_{\min, 0-60\,cm} \tag{3}$$

in which

N-fertilization	=	Amount of N, applied in February-April as mineral fertilizer or as manure with a comparable release	[kg.ha^{-1}]
$N_{\min,\,0\text{-}60\,cm}$	=	Amount of mineral N, assessed in February in the soil layer 0-60 cm (partly as a result of earlier manure applications)	[kg.ha^{-1}]

The crop takes up more than the available amount of N in the soil layer 0-60 cm in February; the factor '1.7' is partly explained as mineralization during the growing season and uptake from deeper soil layers (Smit and Van der Werf, 1992). Equation 3 does not describe the effects of a non-optimal N-level on yield and quality as required in a decision support system. Therefore, relationships between N-available on the one hand and yield, quality, environmental and financial parameters on the other had to be derived.

The model

In PIEteR, the growing season is divided into three phases: the emergence phase, the phase between emergence and canopy closure and the production phase (Smit and Struik, 1995). In the first two phases, temperature is regarded as the main determining factor for emergence and leaf formation rates; in the third phase, root and sugar production rates are mainly determined by the daily amount of global radiation. Light use efficiency functions play an important role in the translation of radiation levels into root and sugar production. These functions depend on the time after GPD [5], as shown in Figure 1. A soil moisture balance modifies the respective rates in every phase.

The derived functions for relative root and sugar yield, sugar content, (K + Na) and α-amino-N contents and for absolute fresh leaf yield and N-amount in crop residues were included in PIEteR. The extractability index and the operating receipts were not directly

[5] GPD is the 'Growth Point Date', which nearly coincides with the day on which the canopy closes, i.e. leaves from adjacent rows touch. Details are given in Smit and Struik (1995).

modelled, but calculated from the respective yield and quality parameters. PIEteR is written in TURBO-PASCAL, version 6.

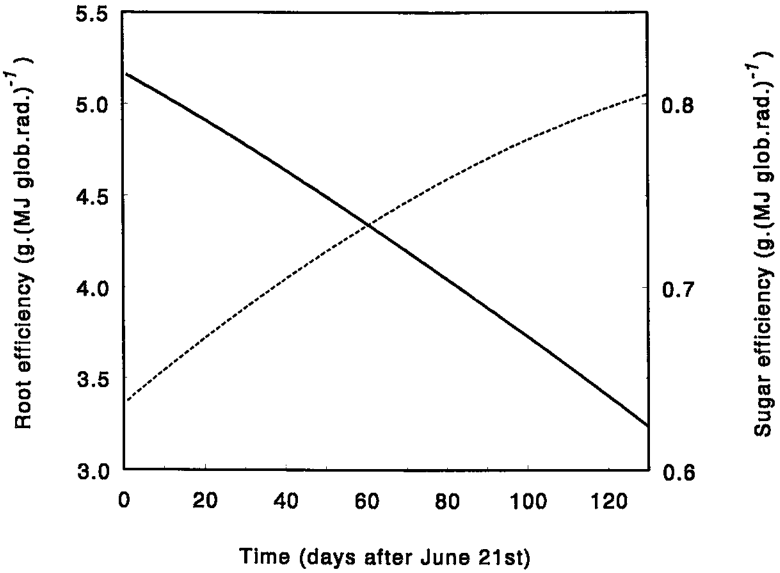


Figure 1. Development over time (after GPD) of the efficiency of fresh root and sugar production.

Effects of nitrogen

The Dutch Sugar Beet Research Institute (IRS, Bergen op Zoom) carried out field experiments with different levels of N-fertilization in different years and regions in The Netherlands. Table 1 gives materials and methods and the resulting data, which included fresh root, sugar and (estimated) fresh leaf yields; sugar, (K + Na) and α-amino-N contents; and N_{min}-levels after harvest; these were analysed in relation to level of N-fertilization and N_{min} in different soil layers in February. After a first analysis it was decided to concentrate on relative parameters, i.e. to express yields and contents in average values per experiment [6],

[6] An experiment is here defined as a set of N-applications at one field and in one year.

except for fresh leaf yield. To calculate the extractability index according to Van Geijn *et al.* (1983), the average values of root yield, sugar content, (K + Na) and α-amino-N contents in the calibration data set were used for the relative value of 100% (Table 1). The operating receipts were calculated, applying the sales system in Table 1 and using the average extractability index in the data set.

Third-order relationships between 'N-available' and different yield and quality parameters were derived with the non-linear estimation procedure 'NLIN' in SAS (SAS Institute, 1988).

Different (unpublished) field experiments of the Department of Agronomy provided data on the N-content of roots, leaves (blades and petioles) and crowns of sugar beets at different N-rates and at different soil types. Methods and materials of the applied N-analysis are given by Walinga *et al.* (1989). In one of these experiments (in 1993) we applied three levels of N-fertilization in four replicates: 0, 100 and 200 kg.ha^{-1} N, whereas $N_{min,\ February}$ was 50 kg.ha^{-1}.

Total N-amounts in crop residues were modelled by combining the fresh leaf and crown yields with their respective N-contents. We had only data on crowns from the 1993 field experiment, so that the simulations for crown yield and crown N content could not be validated.

Tests

Root and sugar yields, sugar content, extractability parameters and post-harvest N-levels in crop residues were predicted with and without corrections for available N. In addition, the operating receipts per ha were calculated in order to evaluate the integrated effect of the N-module on the quality of farm economic predictions as a basis for decision support.

In the test, an independent data set consisting of results from 100 (experimental) fields was used; 96 of these contained a complete set of IRS-trials on N-supply on Dutch clay, sandy and reclaimed peat soils in the period 1980 - 1982; only a few fields with 'abnormal' split applications of nitrogen were not taken into account. Those that received a supply at a normally recommended level have already been described by Smit and Struik (1995). Four fields were located at the Experimental Station for Arable Farming and Field Vegetable Production (PAGV), Lelystad, yielding data of fields on clay soil which were accurately sampled for modelling purposes during 1978 and 1981 - 1983. Additional information is given in Table 2.

The prediction error, the absolute difference between observed and predicted values, was calculated for every variable and every field, expressed in units and as percentages of the observed value, and averaged over all fields included. In addition, linear regression

Table 1. Information on the data set used for calibration of relationships between N-level and different yield and quality parameters, included in an N-module of PIEteR.

Sources of data:

A IRS-data of 10 fields * 5 N-rates during the period 1990 - 1992 (Van der Beek and Wilting, 1994); we used the data of full width application above 50 kg $N.ha^{-1}$.

B IRS-data of 107 fields * 6 N-rates during the period 1977 - 1979 (not published); materials and methods were the same as for A; only dates and sites were different, and row application was not studied.

More information on materials and methods applied by IRS is given by De Nederlandse Suiker-industrie (1989; the current paper also gives information for later years).

Average values for the combined data set were:

Root yield:	57.5 $tonnes.ha^{-1}$
Sugar content:	17.0%
Fresh leaf yield [1]:	35.9 $tonnes.ha^{-1}$
(K + Na) content:	33.2 mmol.$(100\ g\ sugar)^{-1}$
α-amino-N content:	15.8 mmol.$(100\ g\ sugar)^{-1}$
Extractability index [2]:	87.6
Operating receipts [3]:	7.35 $kfl.ha^{-1}$

1 Given for most fields in data set B

2 According to equation 1

3 Sales system:
0.115 kfl (1 kfl = 1000 Dutch guilders) per net ton of sugar beets, corrected with 9% per percent sugar content above or under 16% and with 0.9% per point extractability index above or under 85; penalties for dirt tare were not included in our calculations. This system was used in 1993 by Suiker Unie, one of the sugar beet processing companies in The Netherlands (Menu, 1993).

analysis was applied to test how well the predicted values matched the observed ones. We used the explained variance (R^2) as a measure.

Besides the values at final harvest, the (K + Na) and α-amino-N contents and extractability indices during the season were studied. The applied version of PIEteR included effects of plant density as well, described by Smit *et al.* (1995).

Results

The model

Figures 2A-2B show the relationships between available nitrogen and relative yield, quality and financial parameters, derived from the fields described in Table 1. We assumed that these fields represented The Netherlands as a whole. Root and sugar yields were optimal at 240 and 200 kg $N.ha^{-1}$, respectively. When the N-rate increased by 15 $kg.ha^{-1}$ over the N-availability range 100 - 250 $kg.ha^{-1}$, the sugar content and the extractability index decreased by 0.08% and 1.9 units respectively, and the (K + Na) and α-amino-N contents increased by 0.35 and 0.83 mmol.(100 g $sugar)^{-1}$ respectively, assuming average values of 17%, 87.6 and 33.2 and 15.2 mmol.(100 g $sugar)^{-1}$, respectively. The operating receipts were optimal at 180 $kg.ha^{-1}$. The shape of the curves for extractability and receipts changed beyond 215 $kg.ha^{-1}$ as a result of α-amino-contents exceeding the threshold value of 17 mmol.(100 g $sugar)^{-1}$.

The amount of total N in crop residues immediately after harvest was calculated from the fresh leaf yield by assuming a nitrogen content of 0.30% for both sandy and clay soils (J. Vos and P. van der Putten, WAU, pers. comm., 1994). The amount of total nitrogen in crop residues increased with increasing N-availability, similarly to the fresh leaf yield. An analysis of the N-availability in February on the one hand and the post-harvest level of residual mineral N in the soil layer 0-60 cm on the other showed that there was no relationship between the two.

Some of the results of the 1993 field experiment for the plots with 100 $kg.ha^{-1}$ (close to the recommendation in Equation 3) are given in Table 3, including the simulated values for this experiment. We assumed and generalised that the amount of remaining N in crowns was linearly related to fresh root yield, which was 8.22 $kg.m^{-2}$ in this case.

Tests

The results of field specific simulations with and without N-correction are given in Table 2. When N-corrections were included in PIEteR the explained variance of all parameters increased. For root and sugar yields, sugar, (K + Na) and α-amino-N contents and operating receipts the mean prediction error decreased. The prediction error remained more or less constant in the case of extractability index.

Figures 3A-3E show that all parameters were overestimated at low values and underestimated at high values. Smit *et al.* (1995), using the same data set, showed that the integrating parameter, operating receipts, was overestimated in about 55% of the predictions. The predicted course of the quality parameters during the season was in some cases

Table 2. Test results of PIEteR over 100 fields, with and without correction for N-availability (N-available = $N_{min,\ February} + N_{fertilizer}$).

Test [A]	Var. [B]	Results		Mean prediction error		Explained variance (R^2, %)
		Observed	Simulated	(kg.m^{-2}, %, mmol, kfl)	(%)	
1	Root	6.13	6.30	0.78	14.9	40.4
2	Root	6.13	6.31	0.75	14.1	43.2
3	Root	6.13	6.27	0.67	11.5	60.4
1	Sugar	1.04	1.07	0.12	13.9	45.7
2	Sugar	1.04	1.06	0.11	12.6	51.9
3	Sugar	1.04	1.06	0.11	10.9	64.7
1	S.cont	16.9	16.9	0.7	4.0	4.0
2	S.cont	16.9	16.8	0.7	3.9	8.6
3	S.cont	16.9	16.9	0.5	3.1	31.6
1	K+Na	29.51	34.19	6.05	21.7	42.1
2	K+Na	29.51	33.36	5.37	19.1	48.7
3	K+Na	29.51	33.15	5.19	18.3	50.7
1	αN	12.49	13.76	4.76	48.0	0.1
2	αN	12.49	13.19	4.49	44.0	0.2
3	αN	12.49	12.82	3.13	26.8	40.0
1	Extr	89.5	88.2	2.4	2.7	26.7
2	Extr	89.5	88.5	2.1	2.4	28.9
3	Extr	89.5	88.4	2.1	2.5	45.1
3	Leaf	3.67	3.45	0.61	17.1	53.6
3	N-leaf	85.8	91.8	23.8	40.4	44.1
1	Pay	7.81	7.99	0.94	13.6	40.5
2	Pay	7.81	7.96	0.86	12.2	50.1
3	Pay	7.81	7.94	0.76	10.3	63.9

[A] 1 = without corrections for plant density and N-availability
2 = with corrections for plant density, but not for N-availability
3 = with corrections for both plant density and N-availability

Additional information over 100 fields:

- Average sowing date:	day 98 (8 April)
- Average simulated GPD:	day 175 (24 June)
- Average plant density (spring):	7.6 plants.m^{-2}
- Average amount of N in soil layer 0-60 cm (February):	51 kg.ha^{-1}
- Average level of N-fertilization:	127 kg.ha^{-1}.

[B]

'Root'	= fresh root yield	[kg.m^{-2}]
'Sugar'	= sugar yield	[kg.m^{-2}]
'S.cont'	= sugar content	[%]
'K+Na'	= (K + Na) content	[mmol.(100 g sugar)$^{-1}$]
'αN'	= α-amino-N content	[mmol.(100 g sugar)$^{-1}$]
'Extr'	= extractability index	[-]
'Leaf'	= fresh leaf yield	[kg.m^{-2}]
'N-leaf'	= Amount of N in leaves	[kg.ha^{-1}]
'Pay'	= Operating receipts [3]	[kfl.ha^{-1}]

[C] The sales system is explained in footnote [3] of Table 1.

Table 3. Observed and simulated results of plots with recommended N-rate [1] in a field experiment in Wageningen in 1993. The observed values are means of four replicates.

Parameter	Observed	Simulated
Fresh leaf yield (kg.m^{-2})	3.8	3.6
Dry matter content leaves (%)	12.6	-
N content leaves (fresh basis, %)	0.30	0.30
Residual N-amount in leaves (kg.ha^{-1})	114	109
Fresh crown yield (kg.m^{-2})	0.88	-
Dry matter content crowns (%)	24.2	-
N content crowns (fresh basis, %)	0.24	-
Residual N-amount in crowns (kg.ha^{-1})	21	21
Total residual N-amount in leaves and crowns (kg.ha^{-1})	135	130

[1] N-fertilization rate = 100 kg.ha^{-1}; $N_{min,\ February}$ = 50 kg.ha^{-1}.

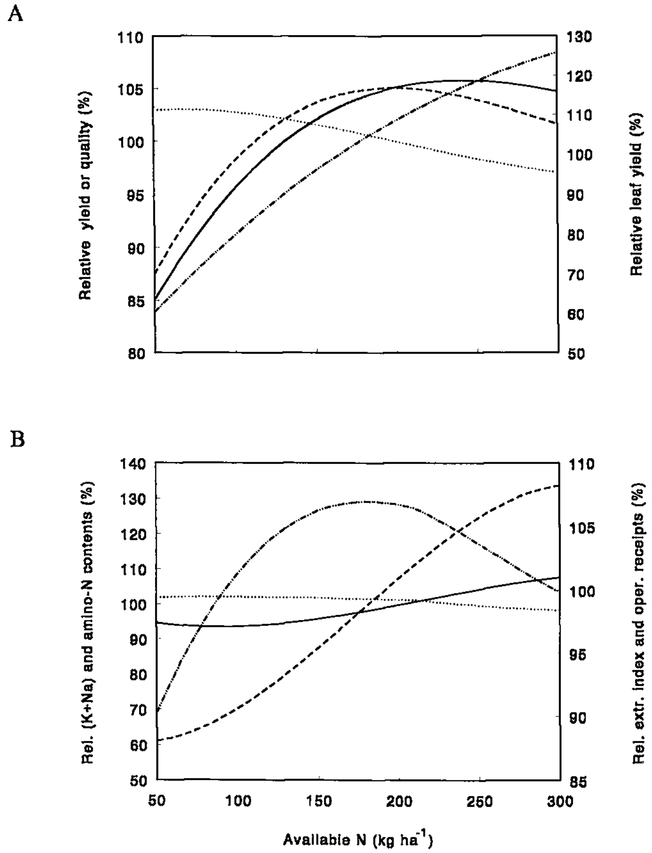
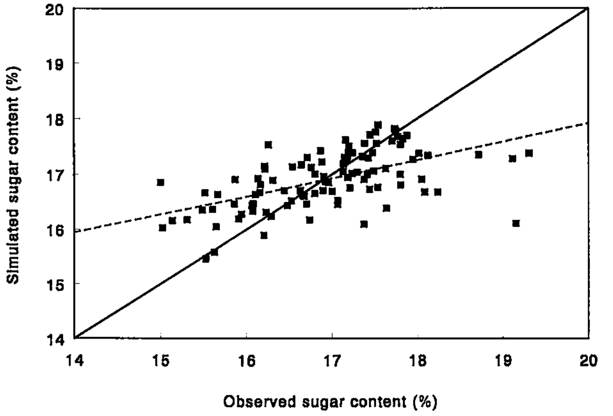
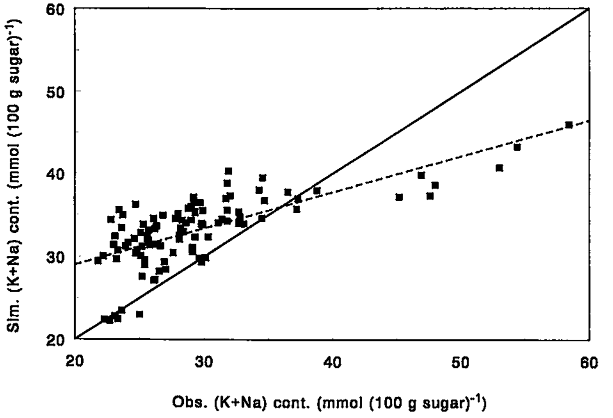


Figure 2. Relative yield, quality and financial parameters vs. available nitrogen (N-avail = $N_{min,\ February}$ + $N_{fertilizer}$). A: Root, leaf and sugar yield, and sugar content; the equation for fresh leaf yield is given for absolute values ('Abs. leaf', in tonnes.ha^{-1}). Note that the equation describes absolute leaf yield (as included in the model), whereas the curve gives values relative to the means in the data set (Root = 69.5 + 0.366 * N - 1.16E-3 * N^2 + 1.11E-6 * N^3 (R^2 = 62.3%); Sugar = 70.0 + 0.424 * N - 1.61E-3 * N^2 + 1.83E-6 * N^3 (R^2 = 54.3%); Sugar content = Sugar/Root * 100%; Abs. leaf yield = 12.8 + 0.183 * N - 3.23E-4 * N^2 + 1.92E-7 * N^3 (R^2 = 61.6%);
B: (K + Na) and α-amino-N contents, extractability index (according to Van Geijn *et al.*, 1983), and operating receipts (receipts: according to footnote 3, Table 1; K + Na = 100 - 0.169 * N + 1.21E-3 * N^2 - 1.88E-6 * N^3 (R^2 = 49.9%); αN = 65.5 - 0.260 * N + 3.80E-3 * N^2 - 7.27E-6 * N^3 (R^2 = 72.9%). (A: ___: root yield; - - -: sugar yield; . . . : sugar content; - . . - . . -: leaf yield; B: ___: (K + Na) content; - - -: α-amino-N content; . . .: extractability index; - . . - . . -: operating receipts).

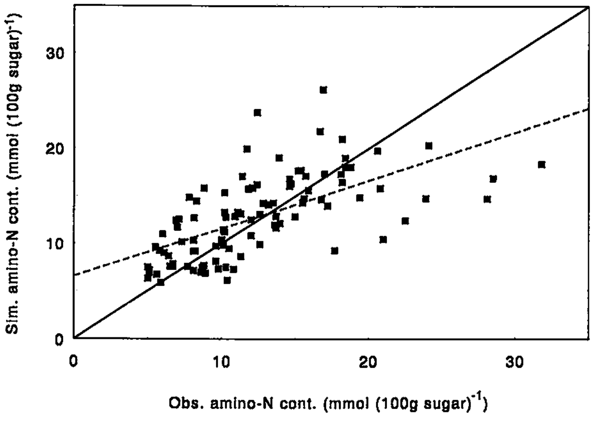
A


Simulated sugar content (%)
Observed sugar content (%)
14
15
16
17
18
19
20

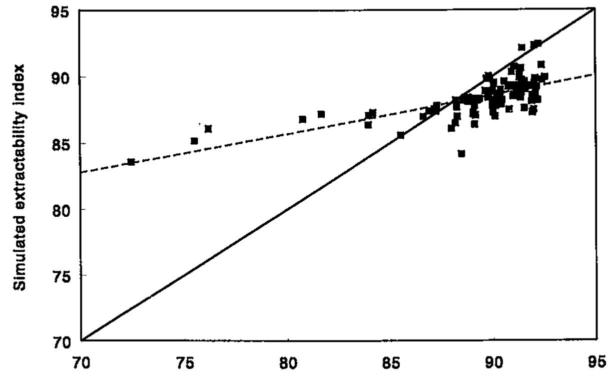
B


Sim. (K+Na) cont. (mmol (100 g sugar)$^{-1}$)
Obs. (K+Na) cont. (mmol (100 g sugar)$^{-1}$)
20
30
40
50
60

C


Sim. amino-N cont. (mmol (100g sugar)$^{-1}$)
Obs. amino-N cont. (mmol (100g sugar)$^{-1}$)
0
10
20
30

D



E

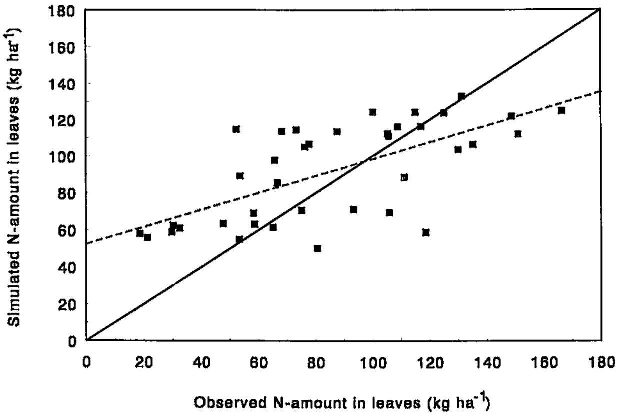


Figure 3. Simulated (with model PIEteR) vs. observed quality and environmental parameters. A: sugar content (n = 100; R^2 = 31.6%); B: (K + Na) content (n = 100; R^2 = 50.7%); C: α-amino-N content (n = 100; R^2 = 40.0%); D: extractability index (according to Van Geijn *et al.*, 1983; n = 100; R^2 = 45.1%); E: amount of total residual N in leaves (n = 38; R^2 = 44.1%).

A

B

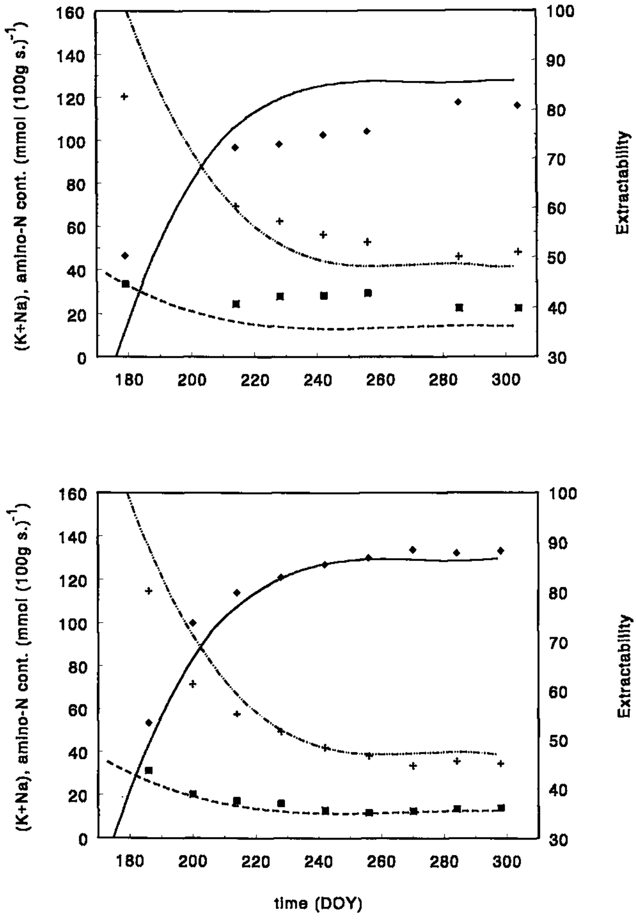


Figure 4. Observed and simulated (with model PIEteR) (K + Na) and α-amino-N contents and extractability index (according to Van Geijn *et al.*, 1983) vs. time. A: field with relatively poor simulation results; B: field with relatively good simulation results. (+ : Observed (K + Na) content; ■ : Observed α-amino-N content; ◆ : Observed extractability index (according to Van Geijn *et al.*); __ __ __ : Simulated (K + Na) content; - - - : Simulated α-amino-N content; - . . . - : Simulated extractability index)

not very accurate, but the extractability index at final harvest had mean prediction errors of only 2.5%. Figures 4A-4B show the course for two fields with relatively poor and good simulation results. The prediction was better in the end of the growing season than in the beginning.

Discussion

The model

According to Bosch (1986) the optimal N-rate for root and sugar production ranges from 120 to 160 $kg.ha^{-1}$. Assuming an N-amount of 50 $kg.ha^{-1}$ in the soil layer 0-60 cm in February, the optimal N-availability ranges from 170 to 210 $kg.ha^{-1}$. Van Burg *et al.* (1983) stated that the optimal N-level is always lower for financial returns than for root and sugar yields, being 180, 240 and 200 $kg.ha^{-1}$ in our analysis, respectively. According to Last *et al.* (1994) the economic optimum in English trials was 128 kg $N.ha^{-1}$ on average.

Compared to our results, Bosch (1986), Van Burg *et al.* (1983) and P. Wilting (IRS, pers. comm., 1995) reported similar values for sugar content decrease with increasing N-rates: 0.1%, 0.07% and 0.06-0.09% per 15 kg $N.ha^{-1}$, respectively. Sugar content decreases with increasing nitrogen supply (until a certain limit) due to an increase of root cell size; there is no specific effect on sugar storage itself (Milford and Watson, 1971; Watson *et al.*, 1972), unless the absolute root fresh yield declines as well.

P. Wilting (IRS, pers. comm., 1995) and Van der Beek (1991) found similar values as we did for the effects of N on the α-amino-N content and the extractability index. However, according to P. Wilting (IRS, pers. comm., 1995) there is no uniform effect of nitrogen on the (K + Na) level; in certain soils, for example sandy and reclaimed peat soils in The Netherlands with low K contents (especially in deeper soil layers), the K content (in mmol.$(100 \text{ g sugar})^{-1}$) does not significantly increase with increasing N-level.

Operating receipts were maximal when the N-availability was 180 $kg.ha^{-1}$, or the N-fertilization rate 130 $kg.ha^{-1}$. Applying Equation 3 the normally recommended rate would be 135 $kg.ha^{-1}$, assuming 50 kg $N_{min}.ha^{-1}$. The recommended N-rate according to Equation 3 is higher than our optimum for soil N-amounts less than 57 $kg.ha^{-1}$ and lower beyond 57 $kg.ha^{-1}$ (Figure 5). Costs of N-fertilizer were not taken into account in both calculations; correction for costs of fertilizer decreases the optimum N-rate by 20 $kg.ha^{-1}$ (P. Wilting, IRS, pers. comm., 1995) [7]. Equation 3 is a rough estimate, because it does not take temperature, moisture content and type of soil into account, nor the use of organic manure in the past, all of them influencing the level of mineralization (IB-DLO, 1991). In Belgium

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[7] Valid for the 1993 price ratio between sugar beet and fertilizer.

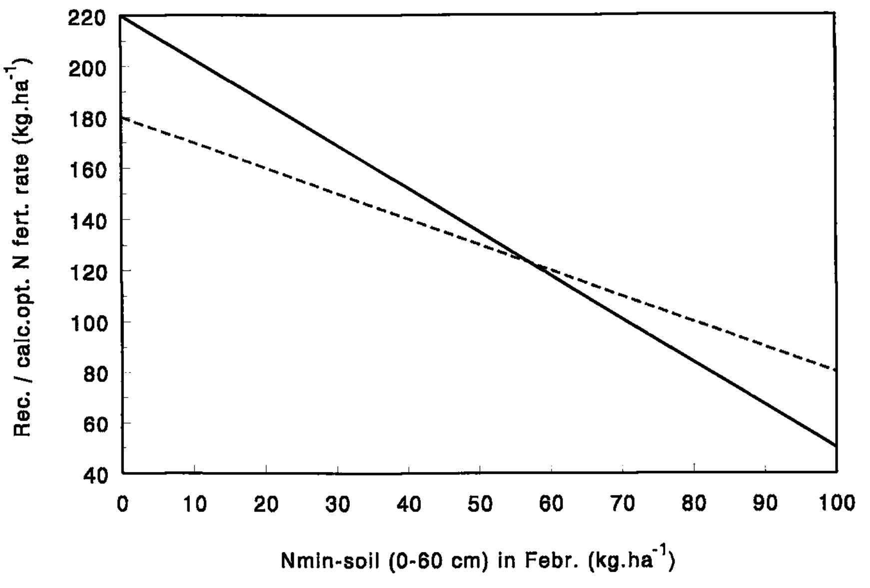

Figure 5. Recommended N-fertilizer rate vs. $N_{min,\ 0\text{-}60\ cm}$ according to the official recommendation in The Netherlands and calculated optimum from statistical analysis. (___ : Official recommendation; - - - : calculated optimum)

(N-index, Vandendriessche et al., 1992) and France (N-balance, Viaux, 1981), the N-recommendation systems include N-mineralization, the use of organic manure in the past and factors with a negative influence on N-mineralization (e.g. pH and soil structure). The equation for Spanish N-recommendations contains a (negative, linear) factor for organic matter content of the soil, and irrigation and organic fertilization are also taken into account (Barbanti, 1994).

The dynamics of processes leading to N-supply (mineralization) or N-losses (leaching, denitrification) during the growing season were not taken into account in the model. Including these would probably improve the results of the N-module of PIEteR as well as the official recommendations; however, both processes are very difficult to model because of their complexity (De Willigen *et al.*, 1992). Neither was attention paid to possible supply of N in organic form, although up to two thirds of the total amount of N required can be applied in this form on sugar beets (B. Ruiter, SLM, pers. comm., 1992); manure application in spring is common on most sandy, reclaimed peat and loess soils in The Netherlands. N from organic sources needs more time to become available to the crop than fertilizer-N, which makes it rather difficult to assess the optimal amount of additional fertilizer-N. Nevertheless, the Dutch Nutrient Management Institute (NMI) has done an effort to optimize the use of animal manure and fertilizer in a so-called Integrated Fertilization Programme (Van Erp and Oenema, 1992).

The environmental consequences of N-fertilization were not studied in full detail, but we focused on the amounts of N which had been observed in the soil and in the crop residues immediately after harvest. We did not find any relationship between the N-availability in spring and the nitrogen level in the soil after harvest ($N_{min,\ 0\text{-}60\ cm,\ after\ harvest}$). Schröder *et al.* (1994) came to the same conclusion. In general, $N_{min,\ 0\text{-}60\ cm,\ after\ harvest}$ is relatively low; Baumgärtel and Engels (1994) and Van Erp and De Jager (1992) mentioned 40 $kg.ha^{-1}$ in the soil layer 0-90 cm on average. Within the normal N-application range of 0-200 $kg.ha^{-1}$, a limit of 70 $kg.ha^{-1}$ in the soil layer 0-100 cm as proposed to the Dutch government will not be exceeded (Goossensen and Meeuwissen, 1990). An important research topic concerns the fate of the nitrogen in the crop residues. If it is mineralised during the winter, it may partly be lost through leaching. Van Erp *et al.* (1993) found that the C/N-ration of the residues is an important factor, which in turn is to a large extent determined by the weather conditions during the growing season, the amount of dry matter produced and the amount of mineral nitrogen available during the growing season. The date of incorporation of the residues is also important; the later this date, the smaller the risk that nitrogen is lost through leaching. Therefore, the proposed limit of 70 $kg.ha^{-1}$ will not be a guarantee that during winter time the nitrogen contents of the upper soil layers will stay low nor that leaching of nitrogen will be avoided.

Simulation of fresh leaf amount at harvest appeared to be a useful method to predict residual N in leaves. The type of harvester machinery and its fine tuning greatly influence the amount of leaf and crown removed. The amount of residual N in post-harvest crop remainders may therefore vary widely, making predictions very difficult. Since the residual N-amount in crowns is much smaller than in leaves, variation of cutting depth will be of minor influence on the total amount of residual N. Values mentioned by other authors are listed in Table 4.

According to Held *et al.* (1994) the farmer should adapt the N-fertilization rate to harvest date. With early harvest the N-rate should be lower than with late harvest. C.E. Westerdijk and J.J. Tick (PAGV, pers. comm., 1989) recommended a reduction of N-rate by 50 $kg.ha^{-1}$ to optimize quality in case of early harvest. Uptake of nitrogen in a final stage of the growing season reduces quality (Vandendriessche *et al.*, 1992). However, Huiskamp (1982) showed that there is no effect of harvest time on nitrogen requirement, and in

Table 4. Yields of crop residues and total nitrogen contents of crop residues. Values at optimal N-fertilization from literature and experiment.

Reference	Dry yield crop residues ($kg.m^{-2}$)	Fresh yield crop residues ($kg.m^{-2}$) [1]	Total N-yield of crop residues ($kg.ha^{-1}$)
Smit & Van der Werf (1992)	0.4	2.67	120
Van Erp & De Jager (1992)	0.55	3.67	127
De Willigen *et al.* (1992)	0.6	4.0	104
Van der Beek (1991)	-	-	120-150
Olssen & Bramstorp (1984)	-	-	100-160
Smit *et al.*, experiments	0.69	4.68	135
Smit *et al.*, model	-	-	130

[1] The fresh yield of crop residues was not given (except in our data set); it was calculated from dry yields by assuming a mean dry matter content of leaves and crowns of 15%.

official recommendations the IRS states that the N-rate is independent of harvest date (P. Wilting, IRS, pers. comm., 1995). All N required is taken up before September. The N-content of the soil layer 0-60 cm in the first half of August should be less than 30 $kg.ha^{-1}$ to ensure a good quality at any harvest time (P. Wilting, IRS, pers. comm., 1995). Therefore, to exceed the earlier mentioned limit of 70 $kg.ha^{-1}$ over a depth of 100 cm (Goossensen and Meeuwissen, 1990) would be unfavourable for the quality of both environment and product. Redistribution from senescent leaves and mineralization will provide sufficient nitrogen after August 15th (Von Müller and Winner, 1980).

The influence of variety on the effects of N was not analysed. Wilting (1993) stated that there is no interaction between N-rate and variety, although the level of yield and quality can be very different for different varieties. Often varieties with high root yields have a relatively low quality and vice versa (CPRO-DLO, 1993). The modelling of fresh leaf yield was based on data of varieties in the 1970's, which were relatively uniform in this aspect. In recent years varieties have become more diverse, also with respect to the fresh leaf yield. Nowadays fresh leaf yield varies between 40 and 75 $tonnes.ha^{-1}$ at maximum. After leaf maximum (normally at the end of August) fresh leaf yield may decrease to an extent which strongly varies with year (M.A. van der Beek, pers. comm., 1995). The question is whether a higher leaf yield corresponds with a lower N-content, making the post-harvest residual N-amount independent of variety, even with the current varieties. This interesting topic requires additional research.

We assumed that the N-content of leaves was independent of N-fertilization rate; however, from unpublished research data (H. Snijders, WAU, pers. comm., 1988; F.A.R. Inghels and A.F.M. Jacobs, WAU, pers. comm., 1994), it can be concluded that with increasing N-rate the accumulation of nitrogen in root and leaves increases more than the fresh root and leaf yields, resulting in an increase of the nitrogen content in the fresh matter. PIEteR probably overestimated the amount of residual N in leaves in case of low observed amounts, since the nitrogen content in the unpublished data was usually lower than 0.3%. More research is necessary to assess the exact relationship between N-availability and N-content of root and leaves.

Tests

N-corrections had more influence on the accuracy of PIEteR than plant density corrections (cf. Smit *et al.*, 1995). Compared to model predictions without N corrections and plant density corrections, the explained variance increased more and the prediction error decreased more through N-correction than through plant density correction for all parameters included except for the (K + Na) content.

One simulation result for sugar content was extremely poor (Fig. 2A). The observed and predicted sugar contents were 19.2% and 15.9% respectively. In 1983, sugar beet was sown late in the very fertile clay soil in Lelystad, because of large amounts of rainfall during spring. Because of a short growing season the ratio between simulated sugar and fresh root efficiency was relatively low (cf. Smit and Struik, 1995). The observed root yield was equal to the predicted root yield (5.6 $kg.m^{-2}$), but the observed sugar yield was higher than the predicted sugar yield (1.1 vs. 0.9 $kg.m^{-2}$). Apparently, the model was not able to correct sugar content for the combination of a late sowing date and a fertile soil.

The quality of sugar beets on soils with high amounts of N and/or K and/or Na at a level deeper than 60 cm and a deep rooting system may be lower than predicted on the basis of $N_{min,\ 0\text{-}60\ cm}$ in February (P. Wilting, IRS, pers. comm., 1995). This was probably true for some of the tested fields, located in the newly reclaimed 'polders'; the observed (K + Na) and α-amino-N contents were much higher than the predicted ones and the extractability index much lower than the predicted one (Figures 3B-3D).

The work presented in this paper resulted in better predictions by PIEteR of yield, internal quality and financial returns for different N-levels. However, the test showed that PIEteR in general overestimated root yield and underestimated extractability index. As a result of the overruling influence of root yield on operating receipts, PIEteR overestimated the financial returns as well. Our aim of decision support requires higher explained variances, especially for root yield, sugar content and operating receipts, and regression equations that resemble Y = X more closely. However, the fields used in the tests had a larger variation in N-availability than usually observed in practice; the intersections of the Y = X and the regression lines were found in the normal ranges of sugar, (K + Na) and α-amino-N contents (Figures 3A-C), the extractability index (Figure 3D) and the operating receipts (Figure 2 in Smit *et al.*, 1995) on commercial fields. Compared to the version of PIEteR without N-module, we made considerable progress. Moreover, fresh leaf yield and total nitrogen content in crop residues were predicted, which will give the farmer insight in the effects of his decisions on environmental aspects of sugar beet growing. Thus, PIEteR was made more capable to support sugar beet growers' decisions by including the effects of N-availability.

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References

Barbanti, L., 1994. New methods of recommending N-fertilizer use to sugar beet in the Mediterranean area. In: Proceedings of the 57th IIRB-winter congress. Brussels, IIRB: 281-294.

Baumgärtel, G. & Th. Engels, 1994. Mineralisation und Auswaschung von Rübenblattstickstoff. *Zuckerrübe* **43**, 125-129.

Beek, van der, M.A., 1991. Over stikstof- en kalivoeding en overige teeltmaatregelen bij suikerbieten. *Meststoffen* **1/2 1991**, 24-29.

Beek, van der, M.A. & A.W.M. Huijbregts, 1986. Internal quality aspects of sugar beet. In: Proceedings No. 252. London, The Fertiliser Society, 20 pp.

Beek, van der, M.A. & P. Wilting, 1994. Onderzoek naar de mogelijkheden van stikstofrijentoediening bij suikerbieten in 1990-1992. Lelystad, PAGV, Verslag nr. 167, 58 pp.

Bosch, H. (ed.), 1986. Teelt van suikerbieten. Lelystad, CAD-AGV/PAGV, Teelthandleiding 21, 98 pp.

Burg, van, P.F.J., M.R.J. Holmes & K. Dilz, 1983. Sugar beet. Nitrogen supply from fertilizers and manures. Den Haag, LBNM, 73 pp.

CPRO-DLO, 1993. 69e Beschrijvende rassenlijst voor landbouwgewassen 1994. Wageningen, CPRO-DLO, 342 pp.

Draycott, A.P., 1993. Nutrition. Nitrogen. In: D.A. Cooke & R.K. Scott (Eds.). The sugar beet crop: science into practice. New York, Chapman and Hall: 241-250.

Egmond, van, F., 1975. The ionic balance of the sugar-beet plant. Wageningen, WAU, PhD-Thesis, 70 pp.

Erp, van, P.J. & K. de Jager, 1992. Drogestofproduktie, N-opneming en N-bemesting van winterrogge geteeld als groenbemester. *Meststoffen* **1992**, 21-30.

Erp, van, P.J. & O. Oenema, 1992. Optimizing the use of animal manure on arable farms. *Meststoffen* **1992**, 75-79.

Erp, van, P.J., A.P. Whitmore & P. Wilting, 1993. Mineralisatie van stikstof uit gewasresten van suikerbieten na de oogst. *Meststoffen* **1993**, 64-70.

Geijn, van, N.J., L.C. Giljam & L.H. de Nie, 1983. α-Amino-nitrogen in sugar processing. In: Proceedings of the IIRB-symposium "Nitrogen and Sugarbeet". Brussels, IIRB: 13-25.

Goossensen, F.R. & P.C. Meeuwissen, 1990. Advies van de Commissie Stikstof. Commissie van deskundigen in opdracht van de ministers van Landbouw, Natuurbeheer en Visserij (LNV), Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (VROM), Verkeer en Waterstaat (V&W). Wageningen, DLO, 153 pp.

Held, L.J., P.A. Burgener, J.G. Lauer & D.J. Menkhaus, 1994. An economic analysis of reducing nitrogen on early harvest sugarbeets. *Journal of Production Agriculture* 7, 4, 422-428.

Huiskamp, Th., 1982. De Invloed van het rooitijdstip op de stikstofbehoefte van drie suikerbietenrassen. Lelystad, PAGV, Verslag nr. 5, 17 pp.

IB-DLO, 1991. Nutriëntendynamiek en bemesting. In: Jaarverslag 1989-1990 IB-DLO, Haren: 9-16.

Jorritsma, 1985. De teelt van suikerbieten. Groene Reeks. Zutphen, Terra, 286 pp.

Last, P.J., A.P. Draycott & M.F. Allison, 1994. Effects of soil mineral nitrogen, soil type and organic manure use on the nitrogen fertilizer requirement and quality of sugar beet. In: Proceedings of the 57th IIRB-winter congress. Brussels, IIRB: 343-351.

Menu, W.J.L., 1993. Wijziging kwaliteitsbetaling suikerbieten. *Maandblad Suiker Unie* **27**, 11, 6-7.

Milford, G.F. & D.J. Watson, 1971. The effect of nitrogen on the growth and sugar content of sugar-beet. *Annals of Botany* **35**, 287-300.

Müller, von, A. & C. Winner, 1980. Neue Ansätze einer standortspezifischen Stickstoffdüngung der Zuckerrübe. I. N-Bedarf der Pflanze und N-Angebot. *Zuckerindustrie* **105**, 1, 64-68.

Neeteson, J.J. & P.A.I. Ehlert, 1989. Environmental aspects of applying inorganic fertilizers to sugar beet. In: Proceedings of the 52nd IIRB-winter congress. Brussels, IIRB: 79-91.

Neeteson, J.J. & K.W. Smilde, 1983. Correlative methods of estimating the optimum nitrogen fertilizer rate for sugar beet as based on soil mineral nitrogen at the end of the winter period. In: Proceedings of the Symposium "Nitrogen and Sugarbeet". Brussels, IIRB: 409-421.

Olsson, R. & A. Bramstorp, 1994. Fate of nitrogen from sugar-beet tops. In: Proceedings of the 57th IIRB- winter congress. Brussels, IIRB: 189-212.

Oltmann, W., M. Burba & G. Bolz, 1984. Die Qualität der Zuckerrübe. Bedeutung, Beurteilungskriterien und züchterische Maßnahmen zu ihrer Verbesserung. Advances in Plant Breeding. Supplement 12 to Journal of Plant breeding. Berlin/Hamburg, Verlag Paul Parey, 159 pp.

SAS Institute, 1988. SAS Language Guide. Release 6.03 Edition. Cary, 1042 pp.

Schröder, J.J., P. Van Asperen, G.J.M. Van Dongen & F.G. Wijnands, 1994. Nutriëntenbenutting en -verlies op de Innovatiebedrijven Geïntegreerde Akkerbouw - resultaten 1990-1993. Wageningen, AB-DLO, Rapport nr. 26, 47 pp.

Smit, A.B. & P.C. Struik, 1995. PIEteR: a field-specific production model for sugar beet growing. *Journal of Agronomy and Crop Science* **175**, 335-348.

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1995. Modelling the influence of plant density on yield, sugar content and extractability of sugar beet. In: Proceedings of the 58th IIRB-congress. Brussels, IIRB: 413-424.

Smit, A.L. & A. van der Werf, 1992. Fysiologie van stikstofopname en -benutting: gewas- en bewortelings-karakteristieken. In: H.G. van der Meer and J.H.J. Spiertz (Eds.). Stikstofstromen in agro-ecosystemen. Wageningen, CABO-DLO, Agrobiologische Thema's 6: 51-69.

Suikerindustrie, De Nederlandse, 1989. Uniforme methode voor gewichtsbepaling, monstername en monsteronderzoek van suikerbieten in Nederland. Amsterdam, CSM: 1-26.

Vandendriessche, H., M. Geypens, J. Bries & G. Hendrickx, 1992. Stikstofbemesting. De stikstofbemesting van akkerbouwteelten in relatie tot het milieu. *Landbouwtijdschrift - Revue de l'Agriculture* **45**, 395-403.

Walinga, I., W. van der Vark, V.J.G. Houba & J.J. van der Lee, 1989. Soil and plant analysis, a series of syllabi, part 7: Plant analysis procedures. Wageningen, WAU, Department of Soil Science and Plant Nutrition, 263 pp.

Watson, D.J., Teruhisa Motomatsu, K. Loach & G.F.J. Milford, 1972. Effects of shading and of seasonal differences in weather on the growth, sugar content and sugar yield of sugar-beet crops. *Annals of Applied Biology* **71**, 159-185.

Willigen, de, P., W.P. Wadman & M. van Noordwijk, 1992. Modelberekeningen omtrent de risico's van minerale stikstofophoping in het najaar bij enige akkerbouwgewassen en vollegrondsgroenten. In: H.G. van der Meer and J.H.J. Spiertz (Eds.). Stikstofstromen in agro-ecosystemen: 87-101. Wageningen, CABO-DLO, Agrobiologische Thema's 6: 87-101.

Wilting, P., 1993. Onderzoek naar de mogelijke interactie tussen rassen en de stikstofbehoefte. In: Jaarverslag 1992. IRS, Bergen op Zoom: 29.

CHAPTER 8

Prediction of various effects of harvest date in sugar beet growing

A.B. Smit, P.C. Struik and J.H. van Niejenhuis

Abstract

One crucial decision in sugar beet growing is determining harvest date. This paper focuses on some aspects associated with harvest date which have to be included in a decision support system for sugar beet growing.

Firstly, we created a module for dirt and crown tare, mainly based on *lutum* (or clay) and soil moisture contents. An independent test of the module showed poor results, because fine tuning of harvest machinery has an overriding effect. Secondly, we analysed the variation in weather conditions during autumn in Wageningen over a period of 38 years. The ranges of future root and sugar production appeared to be so wide, that early predictions of the day on which the sugar quota are exceeded, will not be very reliable. In the third place, risks of severe frost or heavy rainfall in autumn were assessed, based on the same 38 yr data set. The risk of frost damage to unharvested beets proved to be negligible when the crop was harvested before November 10th, as advised by the sugar industry.

The work described in this study makes the model PIEteR (a field specific bio-economic production model for sugar beet, developed for decision support at field and farm level) more applicable by using its potential to analyse the effects of different years and quota options.

Keywords: sugar beet, *Beta vulgaris*, decision support, simulation model, harvest date

1. Introduction

A production model, PIEteR, has been developed as a basis for a decision support system in sugar beet (*Beta vulgaris* L.) growing in The Netherlands. PIEteR means: '**P**roduction model for sugar beet, including **I**nteractions between **E**nvironment and growing decisions, and their influence on the quantitative, qualitative and financial **R**esult'. PIEteR is a relatively simple set of regression models including causal relationships at a relatively high level of aggregation (crop and field). It predicts root and sugar yields, from which sugar content is calculated, (K + Na) and α-amino-N contents, from which the extractability index is calculated, and the operating receipts, which are calculated from the yield and quality parameters (Smit and Struik, 1995b; Smit *et al.*, 1995a). The operating receipts are defined as the amount of money that the farmer receives after delivering his beets, after correction for internal quality (sugar content and extractability index according to Van Geijn *et al.*, 1983).

In PIEteR, four phases of growth and production are distinguished. The first phase or 'emergence phase' starts at sowing date and ends at the day of 50% emergence; its length is mainly determined by temperature, corrected for sub-optimal soil moisture contents. The second phase or 'growth phase' starts at emergence date and ends at the so-called 'growth point date' (GPD), the only well-defined developmental stage in the vegetative sugar beet crop. GPD nearly coincides with the day on which leaves from adjacent rows touch. Details are given in Smit and Struik (1995b). Also the length of the growth phase is mainly determined by temperature, corrected for sub-optimal moisture contents, but the required temperature sums are different for different regions. The third phase or 'production phase' starts at few days before GPD and ends at harvest. The production of root beet and sugar during this phase is mainly determined by radiation intensity, corrected for sub-optimal soil moisture contents and unspecified regional effects. Time dependent efficiency functions translate global radiation levels directly into daily root and sugar production. The fourth phase or 'storage phase' starts at harvest date and ends at the day that the beets are delivered to the sugar industry. The losses of sugar during this phase are mainly determined by temperature. Modelling of the processes during the storage phase has not been included in this paper, because the underlying processes of losses during storage could not be described adequately. PIEteR accounts for plant density and nitrogen effects.

An important decision in sugar beet growing concerns harvest date, since it has major effects on yield, quality and receipts. In the middle of August, the Dutch farmer starts negotiations with the processor to assess the three or four weeks (out of about 13 weeks in total) during which he will deliver the beet. The planning of the company is rather strict in order to operate the factories as efficiently as possible. The influence of the farmer on the delivery periods is limited and mainly determined by historical and distribution patterns. However, a good estimation of the root and sugar yields on August 15^{th} and of the production to be expected afterwards may help the grower to take a clear position in the negotiations. It may also help him to decide about the harvest date(s) and the order in which fields should be harvested, given fixed delivery dates. PIEteR can support him in taking optimal decisions on delivery periods and harvest dates.

Both decisions are influenced by several factors (Buitendijk, 1985; Westerdijk and Zwanepol, 1994):

1 The risks of harvest problems and large dirt tares, both as a result of an increasing precipitation surplus, and the risk of frost damage generally increase after September.

2 The expected changes in yield and internal quality between August 15th and November 15th play a dominant role. Usually, both increase with time until November 10th, so that most farmers want to harvest as late as possible.

3 The difference between marginal returns and marginal costs decreases over time. This is even more true when yield increases beyond the quota. In general, the value of sugar beets then decreases from about 0.115 $kfl.t^{-1}$ to between 0.035 $kfl.t^{-1}$ and 0.075 $kfl. t^{-1}$ (1 kfl = 1000 Dutch guilders). In recent years, the value of surplus sugar beets varied between 0.040 $kfl.t^{-1}$ and 0.050 $kfl. t^{-1}$ (H.C. Antonissen, CSM Suiker, pers. comm., 1995).

In this paper, three aspects associated with harvest date are studied: 1) prediction of tare; a new module was developed and included in PIEteR; 2) prediction of root and sugar yields and receipts during the harvest season, and specifically of the day that the sugar quota are exceeded, and the use of different sources of weather data for this aim, using PIEteR; 3) risk analysis on unfavourable weather conditions during the harvest season, among others studied with the concept of 'workability' or 'being able to harvest without soil structure damage' (Buitendijk, 1985), using PIEteR. The three aspects listed have to be taken into account for optimal decision taking on harvest date, because they provide information on the marginal returns and costs of a delay in harvest.

The work described in this study adds to the applicability of the model PIEteR and makes use of its potential to analyse the effects of different years and quota options.

2. Methods and procedures

2.1. Tare module

Dirt, crown and total tare are defined as a percentage of the gross root yield, the gross yield being the sum of net root yield and total tare amount.

Based on experimental data, we developed a simple module for tare content as a function of soil type, soil moisture content of the upper soil layer (0-25 cm), plant density and root yield. In some equations soil moisture content is expressed as pF (= - log (h), in which h = soil moisture tension (cm)). Data of Van der Beek and Wilting (1994) and of the Dutch Sugar Beet Research Institute (IRS) (Smit *et al.*, 1995b, their Table 1B) and the original data of Floot *et al.* (1992) were analysed to assess equations with a limited number of independent variables. The values for pF and soil moisture content were calculated with

PIEteR (Smit and Struik, 1995b). The data sets contained relatively few fields on sandy soils with enough information for water balance calculations.

Functions for dirt and crown tare contents were derived from experimental data on soil type, *lutum* and moisture contents of the soil, plant density and root yield, as shown in Table 1. *Lutum* is the fraction of the soil texture with particles smaller than 2 μm (clay). In the model, the fraction of soil particles smaller than 16 μm is used, which is about 1.5 x *lutum* content (Huinink, 1994). The available data were divided into those for sandy and clay soils. Different equations were derived for dry and wet clay soils. The difference between dry (high pF-values) and wet (low pF-values) soils was given by threshold pF-values. From our analysis, threshold pF-values of 2.7 and 2.8 were derived for dirt and crown tare, respectively. Three to seven parameters were included in the different equations; e.g. the dirt tare content on sandy soils (T_{ds}) could best be described by Equation 1:

$$T_{ds} = 149 - 32.7\,P_d + 1.95\,P_d^{\,2} - 3.74\,(pF) \quad (n = 20;\ R^2 = 91.2\%) \tag{1}$$

in which

T_{ds}	=	dirt tare (as a percentage of gross weight of sugar beets)	[%]
P_d	=	plant density	[m^{-2}]
pF	=	pF, calculated by PIEteR	[-].

The units of the coefficients 149, 32.7, 1.95 and 3.74 are %, %.m^2, %.m^4 and %.

We assumed equal values for the 'Veenkoloniën' (reclaimed peat soils) as for sandy soils.

In the derived equations, most parameters were included non-linearly as shown in Figures 1-5. The functions of plant density and root yield were mostly quadratic; their minimum values were about 8 plants.m^{-2} and 9 kg.m^{-2}, respectively, depending on the values of the other parameters (Figures 1-3). With increasing *lutum* contents the dirt content increased more than linearly and even stronger with dry soils (pF > 2.7) than with wet soils (pF < 2.7; Figure 4). With increasing soil moisture content the dirt tare on clay soils increased linearly until a pF-value of 2.7 was reached (Figure 5). The exact moisture content at pF = 2.7 depended on soil characteristics. With higher soil moisture contents, the dirt tare decreased less than linearly. The dirt tare module was only valid from the beginning of October; application for earlier dates gave large dirt tares, because of a strong influence of the variable root yield in some of the equations. Minimum dirt and crown tares were 2.8% and 4.4%, respectively, derived at a recent harvest test with various harvesters and favourable soil and weather conditions (Van der Linden and Peeters, 1995).

Table 1 Coefficients of dirt and crown tare functions of soil type, *lutum* content and moisture contents of the soil, plant density and root yield, derived from experimental data.

Parameter	Dirt tare			Crown tare		
	Clay soils		Sandy soils	Clay soils		Sandy soils
	pF < 2.7	pF > 2.7		pF < 2.8	pF > 2.8	
Constant	- 88.7	26.3	149	2.25	- 9.65	98.5
Lutum content (%)	0.732	- 0.800	-	- 0.346	0.387	-
Square (*lutum* content) ($\%^2$)	0.005	0.019	-	0.0045	- 0.004	-
Plant density (m^{-2})	-	- 3.89	- 32.7	4.95	1.42	- 22.8
Square (plant density) (m^{-4})	-	0.224	1.95	- 0.265	- 0.0813	1.43
Root yield ($kg.m^{-2}$)	- 5.06	-	-	- 3.36	-	-
Square (root yield) ($kg^2.m^{-4}$)	0.449	-	-	0.290	-	-
pF	-	-	- 3.74	-	-	- 0.159
Soil moisture content ($cm^3.cm^{-3}$)	161	15.9	-	1.59	-	-
Square (soil moisture content) ($cm^6.cm^{-6}$)	-	-	-	- 49.9	-	-
Inverse (soil moisture content) ($cm^3.cm^{-3}$)	17.2	-	-	-	-	-
Interaction *lutum* content, root yield and soil moisture content ($\%.kg.m^{-2}.cm^{-3}.cm^{-3}$)	- 0.315	-	-	-	-	-
Number of fields	112	32	20	118	26	20
Explained variance (R^2, %)	71.0	89.5	91.2	59.0	90.3	71.8

The tare module was included in PIEteR, (which is written in TURBO-PASCAL 6.0) and tested on 42 field situations. Three of these situations were on heavy clay soils of the Experimental Farm of the Department of Agronomy, Wageningen, The Netherlands, during 1993 - 1995. Additionally, 39 field situations were selected by chance from a data set, described by Wijnands *et al.* (1992, 1995). The field situations covered different soil types (clay, loess, sandy and reclaimed peat soils) and different years (1991 - 1993). The

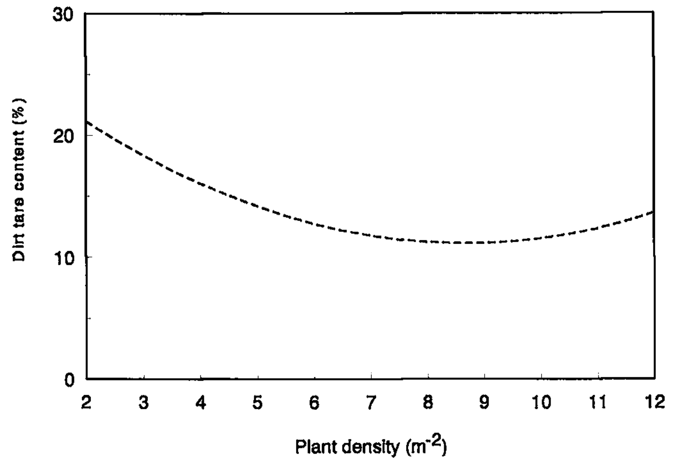

Figure 1. Dirt tare content of dry clay soils (pF > 2.7) as a function of plant density (derived from experimental data); the *lutum* and soil moisture contents were set at 26% and 0.22 $cm^3.cm^{-3}$, respectively.

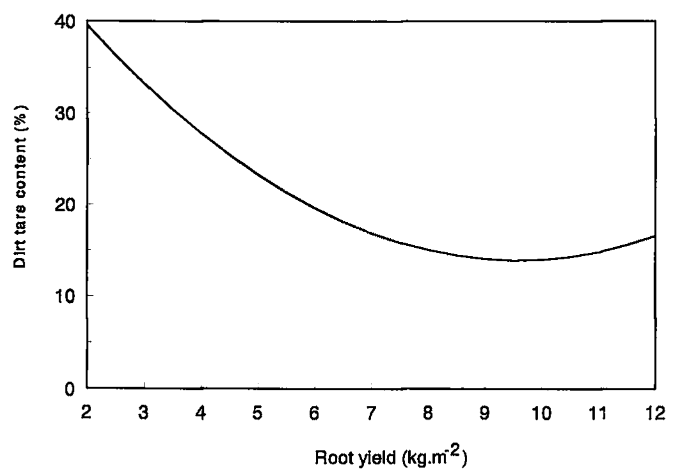

Figure 2. Dirt tare content of wet clay soils (pF < 2.7) as a function of root yield (derived from experimental data); the *lutum* and soil moisture contents were set at 26% and 0.28 $cm^3.cm^{-3}$, respectively.

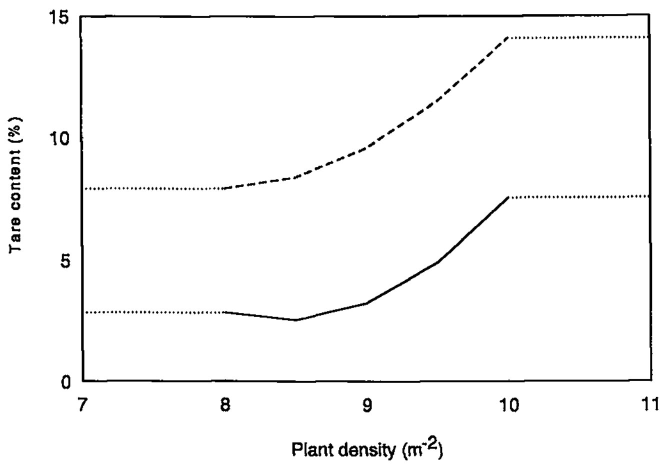

Figure 3. Dirt (__) and crown tare contents (- -) on sandy soils as a function of plant density; pF was set at 2.5; for plant densities out of the studied range [8.0, 10.0], the respective contents were assumed to be constant at the value of the range limit (...).

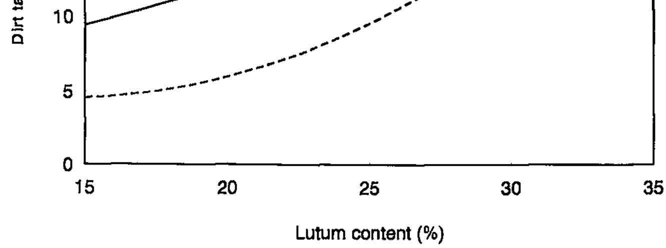

Figure 4. Dirt tare content on clay soils as a function of *lutum* content for wet (__ ; pF < 2.7) and dry conditions (- - ; pF > 2.7); root yield, plant density and moisture contents for wet and dry conditions were set at 7.0 $kg.m^{-2}$, 8.0 $plants.m^{-2}$, 0.28 $cm^3.cm^{-3}$ and 0.22 $cm^3.cm^{-3}$, respectively.

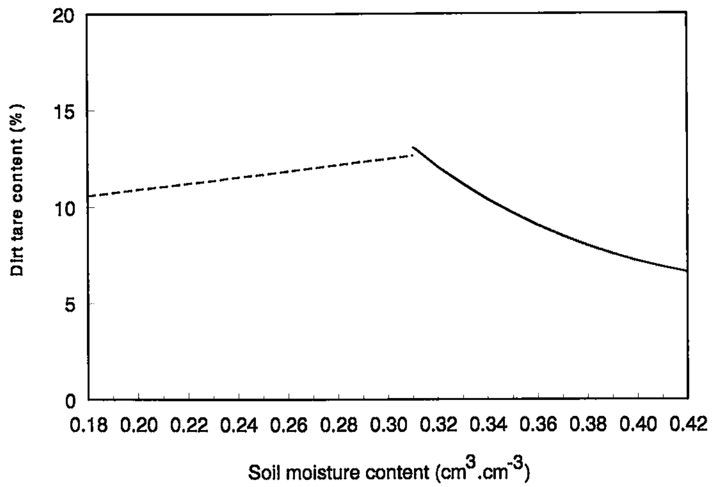

Figure 5. Dirt tare content on clay soils as a function of soil moisture content, for wet (__ ; pF < 2.7) and dry conditions (- - ; pF > 2.7); *lutum* content, root yield and plant density were set at 26%, 7.0 kg.m^{-2} and 8.0 plants.m^{-2}, respectively.

predicted values were compared with the observed ones. The method applied is described in Smit and Struik (1995a). In the test set, only total tare contents were given, so that the dirt and crown tare contents could not be tested separately.

2.2. Uncertainty and application of average weather data

After including the tare module, we ran PIEteR for a field in Wageningen over 38 years (1954 - 1991). This field was located at the experimental farm of the Department of Agronomy, Wageningen Agricultural University, and had organic matter and *lutum* contents of 2% and 37% respectively. For every year simulated, the following assumptions were made: sowing date: day 102 (April 12th); plant density: 8 plants.m^{-2}; mineral N amount in February: 50 kg.ha^{-1}; mineral N fertilization rate: 135 kg.ha^{-1} (the optimum rate, not taking costs of N fertilizer into account).

We calculated average values and standard deviations of several output parameters, concentrating on the changes after August 15th. According to Oude Voshaar (1991), 68% of the observations are found in the range [average - standard deviation, average + standard deviation] and 99.7% of the observations in the range [average - 2 x standard deviation, average + 2 x standard deviation]. A comparison was made with the results of applying 'average' weather files in PIEteR, which would be more practical than running the model for 30 yr or more. The 'average' weather files consisted of the average minimum and maximum temperatures and global radiation intensities per day and a normalised precipitation pattern. In order to avoid a very smooth rainfall pattern, we calculated the average number of 'rain' days per month and the average rainfall per rain day. A rain day was defined as a day with at least 2 mm of precipitation. The differences between the average results over 38 yr and the results of applying average weather files were analysed. The latter were expected to give an overestimation of yield and quality, due to neglect of periods of unfavourable weather conditions in the past.

In the calculations of operating receipts the sugar quota was set at 10 $t.ha^{-1}$; beyond this limit the price decreased from 0.115 $kfl.t^{-1}$ fresh beet to 0.045 $kfl.t^{-1}$ fresh beet (with a sugar content of 16% and an extractability index of 85).

2.3. Risks

Workability or being able to harvest without soil structure damage was defined in terms of soil moisture content. According to Buitendijk (1985) a pF-value of 2.0 could mark the switch from workability to non-workability. A pF-value lower than 2.0 indicates that the soil is too wet for harvest. We applied this concept in a risk analysis, assuming normal distributions of weather parameters.

The pF-values produced by PIEteR over 38 years were used to calculate the probability of at least one non-workable day, having a pF-value lower than 2.0, in the next week. The 38 annual weather files were analysed for the probability of excess rainfall (more than 10 mm per week), low temperatures (average temperatures below 3 °C) and frost (minimum temperatures below 0 °C). We assumed that a rainfall of more than 10 mm in a week increased the probability that harvest with relatively low soil structure damage and relatively low dirt rates becomes impossible. With average temperatures below 3 °C root and sugar production were assumed to be nil. With minimum temperatures below 0 °C, the probabilities of damage to unharvested or uncovered piled beets increase.

3. Results and discussion

3.1. Tare module

Table 2 gives the results of the test on the tare module. The average simulated and observed total tare contents over 42 field situations were 14.0% and 17.2%, respectively. The absolute and relative prediction errors and the explained variance were 6.4%, 37% and 1%, respectively. Figure 6 shows large variations of predicted total tare contents compared

Table 2 Test results (total tare) of the tare module of PIEteR over 42 field situations.

Variable	Total tare (%)		Mean prediction error		Explained variance (R^2, %)
	Observed	Simulated	Absolute (%)	Relative (%)	
Clay and loess	17.4	16.3	6.8	39.5	0.4
Sand and reclaimed peat	16.8	11.0	5.8	34.1	8.5
All field situations	17.2	14.0	6.4	37.2	1.0

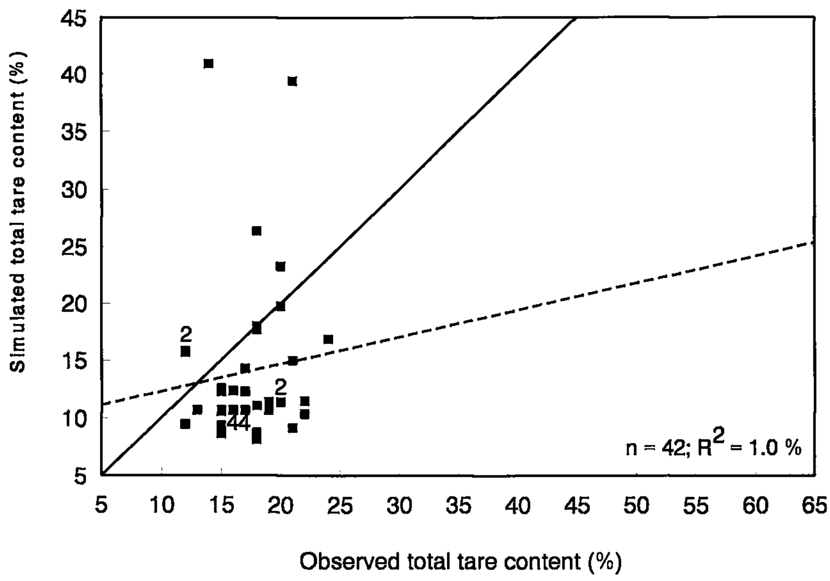

Figure 6. Comparison of simulated and observed total tare contents in a test of 42 fields; numbers give more than one observation with same coordinates (__ : Y = X ; - - : Regression line).

with the observed values. The variance accounted for by the module was higher for sandy and reclaimed peat soils (8%; 18 observations) than for clay and loess soils (0.4%; 24 observations).

The results of the test were very poor. The prediction error for total tare content was large and the explained variance small. The influence of many factors which had not been included in the module, especially 'machinery' and 'man', must have been significant and interacting with the factors included.

With higher yields the average size of the beets generally increases. Consequently, the ratio between beet surface area and beet mass decreases (Ditges, 1990). In our module, an increase of root yield resulted in a change in dirt and crown tare contents. This change was negative under a certain minimum, e.g. 8 $kg.m^{-2}$. Beyond that level the change was positive (Figure 2). Tare content increases with increasing plant density as a result of decreasing average beet size, so that the surface/volume ratio increases (Wevers, 1980).

However, the influence of machinery and its fine tuning is more important than that of root yield and plant density. Some of the 'mechanical factors' are the number of revolutions of the cleaning rotors, the operating depth of the lifting mechanism and the application of brushes (Westerdijk and Zwanepol, 1994; Wevers, 1980). Other factors that were not included in the module, are the effects of the seedbed quality, uniformity of the crop, weed infestation and choice of variety, which all have a significant effect on dirt tare contents (CPRO-DLO, 1994; Westerdijk and Zwanepol, 1994).

Besides *lutum* and soil moisture contents, the soil structure, which was not taken into account, is also important with heavy soils (*lutum* contents higher than 13%). When it is easy to break down clods of soil into smaller particles, then the tare content will be much lower than when the soil structure is compact (Wevers, 1980). With certain combinations of soil structure and soil moisture content, turning up of the soil by the harvester may lead to smearing, resulting in large dirt tares. More research is necessary to quantify the effects of soil structure with different *lutum* and soil moisture contents. Lack of knowledge on this aspect is probably an important source of error in predicting dirt tare of clay and loess soils.

Using average weather files, PIEteR showed that the moisture content of the soil in general increased with time, giving larger dirt tares. However, G.D. Vermeulen (IMAG-DLO, pers. comm., 1995) observed that dirt tare also increased when the moisture content did not increase during the autumn season. Other factors may play a role as well, for example structural changes of the soil (with constant moisture content), changes in volume of the beets (deepening grooves) and the development of young rootlets (Van der Beek and Houtman, 1993).

3.2. *Uncertainty and application of average weather data*

The emergence day, GPD, yield and quality of the crop on August 15^{th} over 38 years and the variation are given in Table 3. Note that the calculations in Table 3 refer to independent parameters. For example, the variance of the changes in extractability index were

Table 3 Model predictions of emergence date, GPD (see footnote 4), yield, quality, financial returns and remaining N on August 15th, and the changes in yield, quality, financial and environmental parameters in the period 15 August - 31 October [1].

Parameter	Results on August 15th			Changes until October 31st		
	Average	Standard deviation		Average	Standard deviation	
		Abs.	Rel. (%)		Abs.	Rel. (%)
Emergence date	119	4.6	3.9	-	-	-
GPD	177	5.2	2.9	-	-	-
Root yield ($kg.m^{-2}$)	4.09	0.49	12.0	+ 2.58	0.69	26.7
Sugar yield ($kg.m^{-2}$)	0.58	0.075	12.9	+ 0.51	0.14	27.5
Sugar content (%)	14.3	0.24	1.7	+ 2.1	0.57	27.1
(K+Na) content (mmol.$(100\ g\ sugar)^{-1}$)	50.23	4.65	9.3	- 12.35	4.46	36.1
α-amino-N content (mmol.$(100\ g\ sugar)^{-1}$)	13.81	0.703	5.1	- 1.29	0.67	51.9
Extractability index (-)	82.8	1.58	1.9	+ 4.3	1.52	35.3
Operating receipts ($kfl.ha^{-1}$)	3.84	0.566	14.7	+ 4.15	1.11	26.7
N after harvest ($kg.ha^{-1}$)	128.1	1.22	1.0	+ 6.6	1.76	26.7

1 PIEteR was used to simulate development and production of a field at the Experimental farm of the Department of Agronomy, Wageningen Agricultural University, assuming day 102 (April 12th) as sowing date, a plant density of 8 $plants.m^{-2}$, a mineral N amount in February of 50 $kg.ha^{-1}$ and an N fertilization rate of 135 $kg.ha^{-1}$.

calculated directly from the results of the 38 computer runs, not from the variance of the determining parameters in PIEteR, i.e. the (K + Na) and α-amino-N contents (based on 100 g sugar).

The average simulated root and sugar yields on August 15th were 4.1 $kg.m^{-2}$ and 0.58 $kg.m^{-2}$, respectively; 68% of the values ranged between 3.1 $kg.m^{-2}$ and 5.1 $kg.m^{-2}$, and between 0.43 $kg.m^{-2}$ and 0.73 $kg.m^{-2}$, respectively. In a similar way, the ranges of the emergence date, GPD, sugar content, the extractability index and the operating receipts can be found in Table 3.

Table 3 also gives the changes in root and sugar yields, sugar, (K + Na) and α-amino-N contents, extractability index, operating receipts and residual N in non-harvestable parts at harvest after August 15th. During the years 1954 - 1991 root yield increased on average by 2.58 kg.m^{-2} between August 15th and October 31st. The increase ranged between 2.27 kg. m^{-2} and 2.88 kg.m^{-2} in 68% and between 1.97 kg.m^{-2} and 3.19 kg.m^{-2} in 99.7% of the years. Operating receipts increased on average by 4.15 kfl.ha^{-1}. Figure 7 shows the differences between the average results over 38 years and the results of average weather files. The operating receipts on October 31st were 7.99 kfl.ha^{-1} and 8.31 kfl.ha^{-1} without quota restrictions, and 7.53 kfl.ha^{-1} and 7.66 kfl.ha^{-1} with restrictions respectively.

National data of IRS-samplings (cf. Smit and Struik, 1995b) from 1984 to 1987 showed that root and sugar yields increased over the period August 12th until October 21st on average by 3.26 kg.m^{-2} and 0.61 kg.m^{-2} respectively, which was more than the comparable values in Table 3 (2.58 kg.m^{-2} and 0.51 kg.m^{-2}, respectively), assuming that the weather

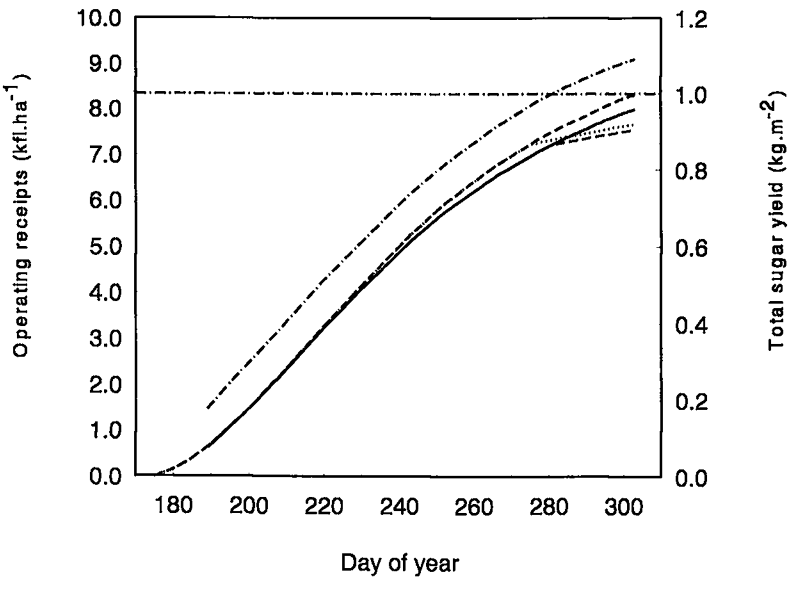

Figure 7. Operating receipts vs. time, calculated in two ways, each with two variants: average values over 38 years (__ : without quota restrictions; __ __ : including quota restrictions beyond a sugar yield of 1.0 kg.m^{-2}), and using an average weather file over 38 years (- - : without quota restrictions; . . : including quota restrictions beyond a sugar yield of 1.0 kg.m^{-2}), and average sugar production after August 15th (first variant), compared with a sugar quota level of 1.0 kg.m^{-2} (__ . __ . (curve: total sugar yield; __ . __ . (horizontal line): sugar quota level of 1.0 kg.m^{-2}.

conditions in Wageningen (in the middle of The Netherlands) were representative for the country as a whole. However, the final root and sugar yields from both sources were almost equal: 6.65 $kg.m^{-2}$ and 1.04 $kg.m^{-2}$ from national data, and 6.66 $kg.m^{-2}$ and 1.09 $kg.m^{-2}$ from the average results of PIEteR of 38 years, respectively. PIEteR therefore overestimated the production until August 15th and underestimated it afterwards. The average GPD from PIEteR was day 177 whereas the estimated GPD from IRS-data was day 181, which explained part of the differences; in PIEteR, light use efficiency depends on the time after GPD (Smit and Struik, 1995b). Both the national IRS-data set and the predictions by PIEteR were based on careful sampling by hand; harvest losses were not included.

According to Scott and Jaggard (1992), the beet sugar production in the period September - November ranged between 0.45 and 0.55 $kg.m^{-2}$ in the UK during the 1980's, which is in agreement with our calculations. They observed a sugar production in November between 0.07 $kg.m^{-2}$ and 0.10 $kg.m^{-2}$. Dutch data on the sugar production in November were not available.

The assumption that historical weather data are representative for the future, gives us the opportunity to calculate average increases of yield, quality and operating receipts between August 15th and October 31st. The operating receipts will increase by 4.15 kfl. ha^{-1}, ranging between 3.70 $kfl.ha^{-1}$ and 4.61 $kfl.ha^{1}$ in two out of three years. The difference between the upper and the lower limit of the range is 0.9 $kfl.ha^{-1}$, providing a great deal of uncertainty on August 15th. However, the degree of uncertainty decreases with time when we let the model use historical weather data until the day of simulation.

The uncertainty increases when estimations are made earlier than August 15th. When only the weather data until sowing date are known, two thirds of the estimations will range between 7.28 $kfl.ha^{-1}$ and 8.74 $kfl.ha^{-1}$, a difference of about 1.5 $kfl.ha^{-1}$. Root and sugar yields will range between 6.11 $kg.m^{-2}$ and 7.21 $kg.m^{-2}$, and between 0.99 $kg.m^{-2}$ and 1.19 $kg.m^{-2}$, respectively. Assuming an average daily sugar production of 45 $kg.ha^{-1}.day^{-1}$ in October (exact data on which Figure 7 was based) a difference of 0.20 $kg.m^{-2}$ corresponds with a difference of 44 days. From August 15th until October 31st the increase of sugar yield will range between 0.45 $kg.m^{-2}$ and 0.56 $kg.m^{-2}$. The difference between both is still 0.11 $kg.m^{-2}$, corresponding to a difference of 24 days of sugar production. On October 1st the 68%-range for sugar yield increase (in $kg.m^{-2}$) was [0.11, 0.15], still corresponding to 9 days of sugar production and making reliable decision support very difficult, especially at the important day of August 15th.

According to the results of 38 simulations with PIEteR, during the last 2.5 months of the growing season on average 39% of the root yield and 47% of the sugar yield was established, representing 52% of the total operating receipts. With given soil properties, nitrogen availability and plant density the production during the late summer and early autumn mainly depends on daily amount of global radiation, according to the model. However, dull conditions and cool temperatures may reduce the efficiency of root and sugar production (Spitters *et al.*, 1990). PIEteR does not correct for these effects on a daily basis, although it includes a general change in the efficiency with time after GPD (Smit and Struik, 1995b).

The difference between the average operating receipts over 38 years and those that resulted from average weather files was 3.9%, partly caused by a difference in root yield (2.3%) and partly by a difference in price, caused by a difference in quality (1.4%). The differences were small in comparison with the prediction error of the operating receipts in the model (13.2%; Smit *et al.*, 1996), so that the use of average weather files was found to be acceptable.

3.3. Risks

Table 4 gives information on risks of rainfall, non-workable conditions, low temperatures and frost in Wageningen. From the 38 yr weather set, we derived the following monthly data on the number of rain days and the average rainfall per rain day (mm): 8 and 8.3; 8 and 8.2; 9 and 7.6 for the months of September, October and November respectively. On average Wageningen had 99 rain days with a total of 763 mm per year. The probability that the next week would bring more than 10 mm of precipitation was relatively high on October 15th (41%) and on November 15th (46%). Until the beginning of November the probability of average temperatures below 3 °C or minimum temperatures below 0 °C was about nil, but increased steadily during November to a value of 45% and 42% at November 30th, respectively. The probability of minimum temperatures below -5 °C, a rule of thumb threshold value for frost damage according to the Dutch sugar industry (Houtman, 1994), was nil until November 1st; after November 15th the probability was greater than nil for every day.

In our analysis a general pF-value of 2.0 was used as a limit for workability for all soil types. Van Wijk *et al.* (1988) specified limit pF-values for different soil types. The current value of 2.0 is specifically safe for sandy loam soils (3-13% of *lutum*); all other soils have a lower limit pF, ranging from 1.7 to 1.9. The probabilities of non-workable days for the heavy clay soil in Wageningen must therefore be lower than mentioned in Table 4. This probability increased with time, up to 82% at the end of October. Hiemstra (1993), however, mentioned that on average the month October has 10 dry days and 20 days with 0-1 mm of rainfall. A higher level of certainty of harvesting on workable days can be obtained by harvesting relatively early or extending the capacity of the available harvester(s) (Buitendijk, 1985).

Table 4 Probabilities of rainfall, non-workable conditions, low temperatures and frost in Wageningen at the end of the growing season (calculated over the period 1954 -1991).

Date	Rainfall in coming week more than 10 mm [1]	pF < = 2.0 [2]	Average temperature below 3°C	Minimum temperature below 0°C
15 September	0.171	0.500	0.000	0.026
22 September	0.373	0.606	0.000	0.026
30 September	0.316	0.682	0.000	0.026
7 October	0.357	0.730	0.000	0.000
15 October	0.408	0.752	0.026	0.053
22 October	0.378	0.817	0.000	0.053
31 October	0.257	-	0.079	0.132
7 November	0.279	-	0.184	0.237
15 November	0.462	-	0.211	0.211
22 November	0.299	-	0.316	0.395
30 November	0.323	-	0.447	0.421

1 In the next week one or more days with 10 mm rain will occur.

2 The pF-value is used as a measure for workability, here defined as a state with pF > 2.0 (Buitendijk, 1985); PIEteR, which was used to calculate pF-values of the top soil layer, ran until October 31st, so that no values could be given for this date and for the month of November.

During the first half of November the sugar beet production can be 0.5 $t.ha^{-1}.week^{-1}$ and in the second half production normally is nil (Westerdijk and Zwanepol, 1994). At the same time frost risks increase. As a consequence the official recommendation in The Netherlands is to harvest before November 10th (Houtman, 1994).

3.4 Harvest date

The selection of optimal harvest dates, given fixed delivery dates, will always be a 'risky' decision. The grower's attitude towards risk (risk averse, risk neutral or risk seeking) plays an important role in weighing the risks of (heavy) rainfall, resulting in soil structure damage and high dirt tare rates, frost or, in extreme situations, not being able to harvest at all. Risk avoiding growers will tend to harvest relatively early, giving up the potential growth during a number of days and accepting extra storage losses compared to later harvests. At the other hand the field will be ready for tillage and sowing of (mostly) winter wheat under favourable soil conditions. However, the yield of winter wheat is not very sensitive to a delay in sowing or to soil structure damage (Habekotté, 1989). In the process of decision making the question whether or not the sugar quota are exceeded plays an important role. Beyond this level, high dirt tare rates affect the profitability of a delay in harvest to a greater extent, especially after November 1st (Van der Linden, 1992). In our calculations, the marginal operating receipts fell from about 0.050 $kfl.ha^{-1}$ to 0.015 $kfl.ha^{-1}$ when sugar production passed the quota level, equalling an increase of tare amount of 2.27 $t.ha^{-1}$ and 0.68 $t.ha^{-1}$ respectively, or an absolute tare content increase of 2.7% and 0.8% respectively, assuming a root yield of 6 $kg.m^{-2}$, an initial tare content of 15% and a tare penalty of 0.022 $kfl.t^{-1}$.

Harvest delay leads to postponed storage losses; as a rule of thumb daily sugar losses are 0.15 $kg.t^{-1}$ $beet.day^{-1}$ (Houtman, 1988, 1992). With a sugar content of 16%, a root yield of 60 $t.ha^{-1}$ and a price of 0.115 $kfl.t^{-1}$ fresh beet, the weekly financial storage losses are 0.045 $kfl.ha^{-1}$, not considering changes in root yield, sugar content and extractability index. More research to predict the exact storage losses and the changes in beet harvest losses is necessary to make the list of factors included in decisions on harvest date complete.

It is difficult to quantify the long-term effects of harvesting under non-workable conditions, possibly affecting the yields of all crops in the rotation by 0-15% (Arvidsson and Hakansson, 1991; Boekel, 1982).

In our study we did not take subsidies on very early or very late delivery into account. These compensate for (part of) the losses of potential growth and for (part of) the storage losses and costs of clamp covering. After the delivery dates have been set, the grower mainly has to take short-term decisions on harvest date which are no longer influenced by the subsidies.

Conclusion

In this paper, three aspects of decisions on harvest date have been studied: 1) prediction of tare; a new module was developed and included in PIEteR. Tests showed that this module needs to be improved; 2) prediction of root and sugar yields and receipts during the harvest season, and specifically of the day that the sugar quota are exceeded, and the use of different sources of weather data for this aim. The ranges of future root and sugar production are so wide, that early predictions on the day of exceeding the sugar quota will not be very reliable. The use of average weather files does not give large errors; 3) risk analysis on unfavourable weather conditions during the harvest season shows that the probability of non-workable days is more than 0.5 from September 15th onwards and that frost damage to unharvested beet is most likely to occur after November 10th. In all three aspects, PIEteR played an important role.

Acknowledgements

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References

Arvidsson, J. & I. Hakansson, 1991. A model for estimating crop yield losses caused by soil compaction. *Soil and Tillage Research* **20**, 319-332.

Beek, van der, M.A. & H.J. Houtman, 1993. Does interaction between varieties and drought stress exist? Proceedings 56th IIRB Winter Congress, Brussels, 10-11 February 1993. Brussels, IIRB: 151-169.

Beek, van der, M.A. & P. Wilting, 1994. Onderzoek naar de mogelijkheden van stikstofrijen-toediening bij suikerbieten in 1990-1992. Lelystad, PAGV, Verslag nr. 167, 58 pp.

Boekel, P., 1982. De bodemstructuur in de moderne akkerbouw. *Bedrijfsontwikkeling* **13**, 1001-1007.

Buitendijk, J., 1985. Effect of workability index, degree of mechanization and degree of certainty on the yield of sugar beet. *Soil & Tillage Research* **5**, 247-257/Technical Bulletins (new series) 36.

CPRO-DLO, 1994. 70e Rassenlijst landbouwgewassen 1995. Wageningen, The Netherlands, 326 pp.

Ditges, K-O, 1990. Untersuchungen zur Reduzierung des Erdanteils bei der Zuckerrübenernte. Bonn, Rheinische Wilhelms-Friedrich-Universität, 235 pp.

Floot, H.W.G., J.G. Lamers & W. van den Berg, 1992. De invloed van de intensiteit van het bouwplan op pootaardappelen, suikerbieten en wintertarwe (vruchtwisselingproefveld FH 82). Lelystad, PAGV-verslag nr. 139, 127 pp.

Geijn, van, N.J., L.C. Giljam & L.H. de Nie, 1983. α-Amino-nitrogen in sugar processing. In: Proceedings of the IIRB-symposium "Nitrogen and sugarbeet", Brussels, Belgium, 16-17 February 1983. Brussels, IIRB: 13-25.

Habekotté, A., 1989. Invloed van het zaaitijdstip op opbrengst en ontwikkeling van winterkoolzaad en granen. Lelystad, Rijkswaterstaat, Flevobericht nr. 302, 85 pp.

Hiemstra, G., 1993. Nog geen reden voor paniek. Rooi niet te vroeg en voorkom structuurbederf. *Boerderij* **79**, 1, 17.

Houtman, H.J., 1988. Inventarisatie van onderzoeksresultaten over de bewaring van suikerbieten. Bergen op Zoom, The Netherlands, IRS, 21 pp.

Houtman, H.J., 1992. Bewaring van suikerbieten. In: IRS/DLV. Artikelen Suikerbieten Informatiedagen 1992. Bergen op Zoom, The Netherlands, IRS: 34-38.

Houtman, H.J.. 1994. Voorkom problemen met vorst in 1994! *Maandblad Suiker Unie* **28**, 10, 7-8.

Huinink, J.Th.M., 1994. Lutum-slibverhoudingen in Nederlandse bovengronden. Ede, IKC Landbouw, 18 pp.

Linden, van der, J.P., 1992. Tarra bij suikerbieten. In: IRS/DLV. Artikelen Suikerbieten Informatiedagen 1992. Bergen op Zoom, The Netherlands, IRS: 26-33.

Linden, van der, J.P. & A.F. Peeters, 1995. Rooidemonstratie: nieuwe technieken oogsten volop belangstelling. *CSM Informatie* **493**, 14-16.

Oude Voshaar, J., 1991. Cursus Toegepaste Statistiek. Versie t.b.v. PHLO-cursus Onderzoekstechniek. Wageningen, The Netherlands, GLW-DLO, 165 pp.

Scott R.K. & K.W. Jaggard, 1992. Crop growth and weather: can yield forecasts be reliable? In: IIRB. Proceedings 55th IIRB Winter Congress, Brussels, 12-13 February 1992. Brussels, IIRB: 169-187.

Spitters C.J.T., B. Kiewiet & T. Schiphouwer, 1990. A weather-based yield-forecasting model for sugar beet. *Netherlands Journal of Agricultural Science* **38**, 731-735.

Smit, A.B. & P.C. Struik, 1995a. The first step towards a decision support system for sugar beet growing: selection of a basic model. *Journal of Agronomy and Crop Science* **175**, 213-220.

Smit, A.B. & P.C. Struik, 1995b. PIEteR: a field-specific production model for sugar beet growing. *Journal of Agronomy and Crop Science* **175**, 335-348.

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1995a. Modelling the influence of plant density on yield, sugar content and extractability of sugar beet. In: Proceedings of the 58th IIRB-congress. Brussels, IIRB: 413-424.

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1995b. Nitrogen effects in sugar beet growing: a module for decision support. *Netherlands Journal of Agricultural Science* **43**, 4, 391-408.

Smit, A.B., G.J.W. Muijs, P.C. Struik & J.H. van Niejenhuis, 1996. Evaluation of a model for sugar beet production by comparing field measurements with computer predictions. *Computers and Electronics in Agriculture* (accepted).

Westerdijk, C.E. & S. Zwanepol (eds.), 1994. Teelt van suikerbieten. PAGV Teelthandleiding nr. 64, 1994. Bergen op Zoom, IRS; Lelystad, PAGV, 121 pp.

Wevers, J.D.A., 1980. Tarrabeperking bij de suikerbietenoogst. *Landbouwmechanisatie* **31**, 1039-1042.

Wijk, van, A.L.M., R.A. Feddes, J.G. Wesseling & J. Buitendijk, 1988. Effecten van grondsoort en ontwatering op de opbrengst van akkerbouwgewassen. Een evaluatie over 30 jaren van de opbrengst van aardappelen en zomergraan op acht bodemprofielen bij vijftien combinaties van ontwateringsdiepte en -intensiteit. Wageningen, ICW-rapporten (nieuwe serie) **31**, 130 pp.

Wijnands F.G., S.R.M. Janssens, P. van Asperen & K.B. van Bon, 1992. Innovatiebedrijven geïntegreerde akkerbouw. Opzet en eerste resultaten. Lelystad, PAGV, Verslag nr. 144, 88 pp.

Wijnands, F.G., P. van Asperen, G.J.M. van Dongen, S.R.M. Janssens, J.J. Schröder & K.B. van Bon, 1995. Innovatiebedrijven geïntegreerde akkerbouw. Beknopt overzicht technische en economische resultaten. Lelystad, PAGV, Verslag nr. 196, 126 pp.

CHAPTER 9

Evaluation of a model for sugar beet production by comparing field measurements with computer predictions

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Abstract

PIEteR is a field specific bio-economic production model for sugar beet, developed for decision support at field and farm level. The model simulates the effects of plant density, N-availability and harvest date on root and sugar yield, internal and external quality, financial return and remaining N in crop residue. The model was tested for a series of 183 commercial and experimental fields in The Netherlands. Average prediction errors for root and sugar yield and financial returns were about 12%, and the variances accounted for about 50%. The data of the commercial fields were also totalled up per farm for each year and compared with the reported ones. The respective prediction errors of total root and sugar yields and financial returns were about 13% and the variances accounted for about 93%.

A sensitivity analysis was carried out on the decisions on plant density, N-fertilization and harvest date and their effects on the output (yield, quality and financial returns). Changes in harvest date had greater effects than changes in N-fertilization and plant density for a field studied.

PIEteR needs to be improved for simulation of sugar content and local yield. For application in a decision support system, giving advice to growers, relative rather than absolute results might be presented. A detailed recording of growing conditions could improve the performance of the model.

Keywords: decision support systems, simulation models, sugar beet, model validation

Introduction

A production model PIEteR has been developed to improve advice in sugar beet growing in The Netherlands. It focuses on N-fertilization and plant density and on harvest and delivery dates. It predicts root and sugar yields, from which sugar content is calculated, (K + Na) and α-amino-N contents, from which the extractability index is calculated, and the operating receipts [1,2], which are calculated from the yield and quality parameters (Smit and Struik, 1995b; Smit *et al.*, 1995a). The model predicts these parameters for every day during the growing season, using historical weather data until the day of simulation and average weather data afterwards (Smit *et al.*, 1996a). The simulated rates of crop growth until canopy closure and of root and sugar production afterwards are adjusted for suboptimal soil moisture contents.

In fact, PIEteR had been developed for laboratory conditions. For calibration of the model, experimental data were used; these had been collected through sampling by hand, so that harvest losses were very small and tare was very different from mechanically harvested fields (Smit and Struik, 1995b). So far, similar data have been used for validation of PIEteR (Smit *et al.*, 1995a,b). However, the model has been developed to give advice to growers and must therefore be able to accurately predict root and sugar yields, sugar content, extractability index, tare and financial returns of commercially grown sugar beet. Therefore, a test on data of commercial fields was required. To make such a test realistic, some adaptations were made (Smit *et al.*, 1996a): 1) a tare module was included in PIEteR; 2) the financial results received more attention since sugar quota regulations were taken into account. Data were available of 8 experimental farms, which covered more or less all regions in The Netherlands. On these farms, sugar beet was grown commercially as well as experimentally. Data of 70 commercial fields were available, on which 'normal cultural practices' had been applied; besides 113 experimental fields were studied in the test, on which one or more factors had been changed for research reasons. The experimental fields were also included in the test to acquire a larger data set. In total, 183 fields were tested. Besides, the data of a field in 1995, not included in the 183 fields, were used for a sensitivity analysis on the input factors N-fertilization, plant density and harvest date. Optimum levels of the three were assessed and the effects of sub-optimal decisions were studied.

In this paper, the model is evaluated through a validation test and a sensitivity analysis.

[1] Defined as the amount of money that the farmer receives after delivering his beets, adjusted for internal quality (sugar content and extractability index according to Van Geijn *et al.* (1983)).

[2] Sugar content has a great effect on financial returns; therefore, it is important to be able to give accurate predictions of this parameter in the first half of August and onwards, so before the start of the harvest season.

Materials and methods

Test on 183 fields

Data were gathered from 183 sugar beet fields; most of which were on regional experimental farms throughout The Netherlands. Data collected included: soil data (clay and organic matter contents); information on sowing, harvest and/or delivery dates; nitrogen fertilization and plant density, and root yields and quality parameters (sugar content, extractability index and tare). Part of the information from commercial fields was obtained through questionnaires. The remaining data originated from field experiments: 1) described in a publication by Van der Beek and Wilting (1994); 2) the original data of Floot *et al.* (1992). Weather files for weather stations of the Dutch Institute for Meteorology (KNMI) as near as possible to the fields tested, were obtained from the Institute for Agrobiological and Soil Fertility Research (AB-DLO), Wageningen. More details about the fields tested are given in the notes of Table 1.

PIEteR was run for the period between sowing and harvest dates with the required input data (on soil properties, weather parameters, sowing and planned harvest dates, plant density and N-fertilization rate). The simulated results were compared with the reported results by regression analysis as described in an earlier paper (Smit and Struik, 1995b). Simulated root yields of commercial and experimental fields were adjusted by - 15% and - 5% respectively to account for the differences between the hand-sampled data on which the model had been based (Smit and Struik, 1995a), and the machine-harvested data of the commercial and experimental fields (P. Wilting, IRS, pers. comm, 1996).

Besides regression analysis, a test procedure of Mitchell and Sheehy (1996) was used to compare simulated and observed values. They calculate the maximum number of absolute prediction errors greater than a limit value set beforehand. This number depends on the total number of observations and the probability interval required. The aim for which the model is developed, determines to a large extent the required accuracy and therefore the limit value for the prediction error. The method can be described by Equation 1 (Mitchell and Sheehy, 1996):

$$P_{(r)} = \frac{n!}{r!\,(n-r)} p^r q^{n-r} \qquad (1)$$

in which:

$P_{(r)}$ = the probability of obtaining a sample with r points outside the envelope of acceptable predicted values;

n = the number of points in the sample;

Table 1 Results of a test of PIEteR on commercial and experimental sugar beet fields in different years and regions.

Test [A]	Parameter [B]	Results				Mean prediction error		Explained variance	X-coef [C]
		Observed			Simulated	($kg.m^{-2}$, %, mmol, kfl)	(%)	(R^2, %)	
		Min	Max	Mean					
1	Root	4.97	9.09	6.38	6.28	0.67	10.5	18.7	0.36
2	Root	3.49	9.82	6.42	5.73	0.92	13.3	65.4	0.60
3	Root	3.49	9.82	6.41	5.94	0.83	12.2	52.4	0.56
1	Sugar	0.80	1.45	1.04	1.06	0.12	11.6	19.0	0.44
2	Sugar	0.56	1.63	1.08	0.97	0.15	13.4	66.2	0.67
3	Sugar	0.56	1.63	1.07	1.00	0.14	12.7	50.9	0.62
1	S.cont	14.4	18.0	16.3	16.8	0.83	5.2	1.6	0.11
2	S.cont	15.5	18.7	16.9	16.9	0.68	4.0	5.1	0.18
3	S.cont	14.4	16.7	16.6	16.8	0.74	4.5	3.7	0.15
1	K+Na	21.1	44.8	33.1	34.6	4.70	14.9	38.0	0.30
2	K+Na	25.1	50.0	34.7	37.0	4.15	12.5	38.5	0.31
3	K+Na	21.1	50.0	34.2	36.1	4.29	13.2	38.0	0.30
1	αN	6.5	16.7	10.9	11.4	1.72	16.6	35.7	0.37
2	αN	3.3	22.0	12.5	11.0	2.79	25.0	38.7	0.34
3	αN	3.3	22.0	12.0	11.1	2.45	22.3	35.9	0.33
1	Extr	86.0	92.9	88.8	88.2	1.3	1.4	16.3	0.31
2	Extr	80.9	91.4	87.9	87.4	1.5	1.7	38.6	0.27
3	Extr	80.9	92.9	88.3	87.7	1.4	1.6	31.0	0.31
1	Tare	6.3	23.0	15.2	14.2	4.3	31.2	0.1	0.03
1	Pay	5.63	10.64	7.69	7.89	0.93	12.5	18.4	0.47
2	Pay	3.99	12.12	8.08	7.23	1.15	13.6	66.7	0.70
3	Pay	3.99	12.12	7.93	7.49	1.07	13.2	50.3	0.64
1	Pay-after	5.43	10.41	7.59	7.89	1.0	13.0	15.8	0.41

Notes: on the following page.

Notes to Table 1:

[A] Test: 1 = commercial fields; n = 70 (except for (K + Na), α-amino-N and total tare contents and payment after tare penalty, for which n = 50, 50, 63 and 63, respectively);

2 = experimental fields; n = 113;

3 = all fields; n = 183 (except for (K + Na) and α-amino-N contents, for which n = 163).

Additional information over 183 fields:

- Average sowing date:	day 104 (14 April)
- Average simulated emergence date	day 121 (1 May)
- Average simulated GPD:	day 179 (28 June)
- Average plant density (spring):	8.5 plants.m^{-2}
- Average amount of N in soil layer 0-60 cm (February):	45 kg.ha^{-1}
- Average level of N-fertilization:	122 kg.ha^{-1}

[B]

'Root'	= fresh root yield	[kg.m^{-2}]
'Sugar'	= sugar yield	[kg.m^{-2}]
'S.cont'	= sugar content	[%]
'K+Na'	= (K + Na) content	[mmol.(100 g sugar)$^{-1}$]
'αN'	= α-amino-N content	[mmol.(100 g sugar)$^{-1}$]
'Extr'	= extractability index	[-]
'Tare'	= Total tare content	[%]
'Pay'	= Operating receipts [D]	[kfl.ha^{-1}]
'Pay-after'	= Operating receipts including dirt tare penalties	[kfl.ha^{-1}]

[C] X-coefficient in the regression equation Y = constant + X-coef * X.

[D] Sales system:
0.115 kfl (1 kfl = 1000 Dutch guilders) per net ton of sugar beets, adjusted with 9% per percent sugar content above or under 16% and with 0.9% per point extractability index above or under 85; penalties for dirt tare were only included in 'Pay-after'. This system was used in 1993 by Suiker Unie, one of the sugar beet processing companies in The Netherlands (Menu, 1993).

p = the true proportion (probability of 0.05) of points outside the envelope in the infinite population of points;

q = the complementary proportion of points inside, 0.95.

The cumulative probability for 0, 1, 2, etc. points outside the envelope is summed until it first exceeds 0.95. Samples with these numbers of points outside the envelope would be accepted.

The data of the commercial fields were in many cases not complete. When delivery date but not harvest date was available, the latter was estimated, assuming a certain length of time between both dates. When the harvest of a certain field was prolonged, data on the surfaces (in m^2 or ha) of the separate areas often lacked, and only the respective yields per separate area were given. The model was then run for the different separate areas with their specific harvest dates, and the observed yields per ha for each area had to be estimated.

Because missing values reduced the quality of the data set, the data of the commercial fields were also totalled up per farm for each year and compared with the reported ones, avoiding the problem of allocating observed yields to certain areas with different harvest dates within a field.

The tare data of the experimental fields could not be used for validation, because they had already been used for calibration of the tare module (Smit *et al.*, 1996a). Therefore, the test for this parameter was limited to the commercial fields.

Decision support

We tested the ability of the model to assess the optimal combination of input parameters studied and applied a sensitivity analysis. Different combinations of N-rates, plant densities and harvest dates were tested at a commercial field on the experimental farm 'De Kandelaar', Biddinghuizen, The Netherlands, in 1995. The radiation data originated from the KNMI-weather station 'De Bilt', but temperature and rainfall were measured at the experimental farm itself. More information on the field and on the combinations applied is given in Table 2.

Results

Test on 183 fields

Table 1 gives an overview of the results of the test on an individual field basis. The prediction errors of root and sugar yields and operating receipts for 183 fields were 12.2%, 12.7% and 13.2%, respectively, and the variance accounted for was a little over 50% for the three. The sugar, (K + Na) and α-amino-N contents had prediction errors of 5%, 13% and 22% respectively and variances accounted for of 4%, 38% and 36%, respectively. The extractability index was predicted with an error of 2% and a variance accounted for of 31%. The tare module, which was only tested on commercial fields, gave a prediction error of 31% and a very low variance accounted for of only 0.1%.

The average simulated root and sugar yields, extractability index and operating receipts over 183 fields were lower than the observed values. For the sugar, (K + Na) and α-amino-N contents the simulated values were higher than the observed ones. In general,

Table 2 Information on the field that was tested, and on the combinations of different N-rates, plant densities and harvest dates; all (120) combinations were applied in the test.

Field:

* Location: Experimental farm 'De Kandelaar', Biddinghuizen, Flevoland, The Netherlands;
* soil type: clay; *lutum* content (particles smaller than 2 μm) = 40 %; organic matter content = 3.4 %;
* sowing date: 12 April 1995; harvest date: 14 November 1995; delivery date: 7 December 1995;
* $N_{min,\ 0\text{-}60\ cm}$ (soil, February) = 19.6 kg.ha^{-1}; N-rate = 112 kg.ha^{-1}.
* Reported yield and quality parameters:
  - root yield = 6.48 kg.m^{-2}
  - sugar content = 16.89 %
  - (K + Na) content = 29.6 mmol.(100 g sugar)$^{-1}$
  - α-amino-N content = 8.3 mmol.(100 g sugar)$^{-1}$
  - extractability index = 89.9
  - tare content = 17 %.
* Calculated financial parameters (cf. Table 5):
  - Operating receipts without quota regulations = 8.38 kfl.ha^{-1}
  - Operating receipts without quota regulations after adjusting for tare penalties = 8.19 kfl.ha^{-1}
  - Penalty for tare = 0.19 kfl.ha^{-1}
  - Operating receipts with quota regulations = 7.93 kfl.ha^{-1}
  - Operating receipts with quota regulations after adjusting for tare penalties = 7.74 kfl.ha^{-1}

Input values applied [1] in simulations with PIEteR:

Background of selected N level	N-rate (kg.ha^{-1})	Plant density (m^{-2})	Harvest date
80% of applied N	90	7	20 October
Applied N	112	8	27 October
Recommended N (PIEteR)	140	9	3 November
Recommended N (official)	168	10	10 November
120% of official recommendation	200	11	
		12	

1 All values of N-rate, of plant density and of harvest date were combined, resulting in 120 runs in total.

both the prediction errors and the variances accounted for were lower for commercial than for experimental fields.

Table 3 shows the results for combined fields per farm. The average simulated total root yield per farm was 21 tonnes lower than the observed one, whereas the average simulated sugar yield was 1 ton higher than the observed one. The resulting simulated and observed total operating receipts were 97.1 $kfl.farm^{-1}$ and 95.9 $kfl.farm^{-1}$, respectively. The simulated and observed total tare amounts were 134 $tonnes.farm^{-1}$ and 161 $tonnes.farm^{-1}$, respectively. The relative prediction errors had the same order of magnitude as the comparable values for field level in Table 1, but the variances accounted for and the X-coefficients for total root and sugar yields and operating receipts were much higher, i.e. higher than 94% and 0.94, respectively.

Applying the test procedure of Mitchell and Sheehy (1996) with a probability level of 95%, 4 out of 34 farms at maximum were allowed to have an absolute prediction error greater than an assumed limit value; this goal was achieved for total root and sugar yields and operating receipts per farm, when the limit prediction errors were set at 19%, 24% and 27% respectively, or 17%, 21% and 22% respectively when a probability of 90% was required.

Figures 1A-E and 2A-D give more information about the observed and simulated values of different parameters at field and farm level, respectively. The observed and simulated root yields had a wider range for experimental fields than for the commercial ones (Figure 1A). For sugar content the ranges were equally wide. However, the experimental fields had more values in the upper ranges (18% and more) and the commercial fields more in the lower ranges (15% or less; Figure 1B). The ranges for extractability index (Figure 1C) were much wider for the experimental fields than for the commercial fields. This was also true for the operating receipts (Figure 1D). For a field with 17% total tare observed, the simulated tare content varied between 10% and 24% (Figure 1E). In Figures 2A-C, overestimation of total root and sugar yields and operating receipts on farm level occurred as frequently as underestimation did. The total tare amount was more often underestimated than overestimated (Figure 2D); the relative prediction error was greater than in Figures 2A-C.

Decision support

In Table 4, the simulated operating receipts for 120 combinations of plant density, harvest date and N-rate are given in the case of quota restrictions. For every combination of plant density and N-rate, the last harvest in the simulations had the highest operating receipts. For all plant density classes applied, an N-rate of 112 $kg.ha^{-1}$ and/or 140 $kg.ha^{-1}$ gave the highest receipts. Figures 3A-B show the results of the test for a plant density of 10

Table 3 Total observed and simulated results for commercial farms, consisting of one or more of the commercial fields in Table 1 [1].

Variable [2]	Results				Mean prediction error		Explained variance (R^2, %)	X-coef [3]
	Observed			Simulated	(tonnes.farm^{-1}, %, kfl.farm^{-1})	(%)		
	Min	Max	Mean					
Root-farm	47.5	1930	785	764	73.0	11.6	96.2	0.90
Sugar-farm	7.0	314	128	129	12.0	13.4	95.3	0.94
Scont-farm	14.6	17.6	16.2	16.8	0.9	5.3	0.4	0.06
Extr-farm	86.1	91.5	88.9	88.2	1.2	1.3	18.0	0.34
Tare-farm	6.0	346	161	134	41.6	34.5	77.1	0.77
Pay-farm	5.0	233	95.9	97.1	9.4	14.4	94.9	0.94

1 Only commercial fields are included in this table; n = 34 (except for 'tare-farm': n = 29).

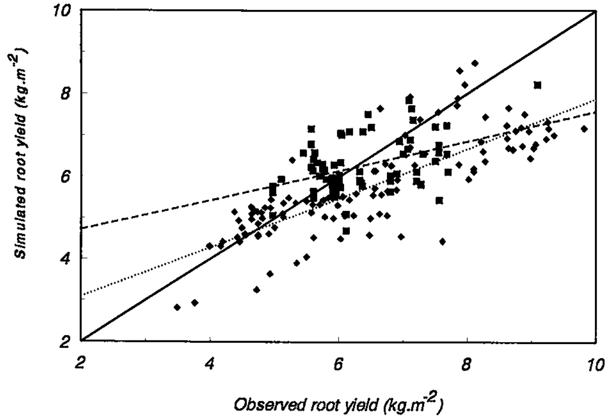
2
'Root-farm'	= fresh root yield	[tonnes.farm^{-1}]
'Sugar-farm'	= sugar yield	[tonnes.farm^{-1}]
'Scont-farm'	= sugar content	[%]
'Extr-farm'	= extractability index	[-]
'Tare-farm'	= total tare amount	[tonnes.farm^{-1}]
'Pay-farm'	= operating receipts [4]	[kfl.farm^{-1}]

3 X-coefficient in the regression equation Y = constant + X-coef * X.

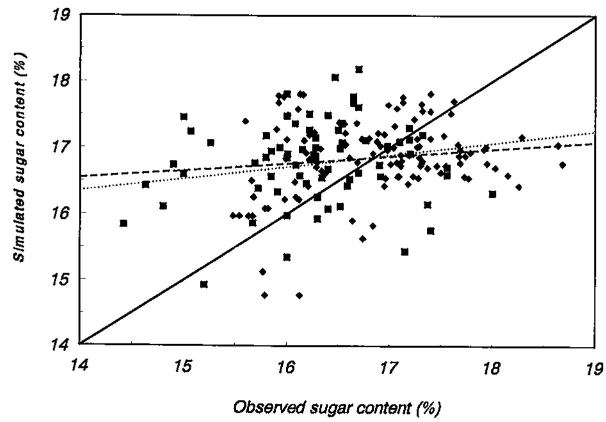
4 Sales system:
0.115 kfl (1 kfl = 1000 Dutch guilders) per net ton of sugar beets, adjusted with 9% per percent sugar content above or under 16% and with 0.9% per point extractability index above or under 85; penalties for dirt tare were not included in the calculations in this table. This system was used in 1993 by Suiker Unie, one of the sugar beet processing companies in The Netherlands (Menu, 1993).

plants.m^{-2} and an N-fertilization rate of 112 kg.ha^{-1}, respectively. In Figure 3A, the simulated operating receipts (Z-axis) for 20 combinations of N-fertilization rate (X-axis) and harvest date (Y-axis) are given. With later harvest, the operating receipts increased independently of N-rate. For all harvest dates, N-rates of 112 kg.ha^{-1} and 140 kg.ha^{-1} gave the best (and similar) results. Figure 3B is similar to Figure 3A, except for the X-axis, which represents plant density. With later harvest, the operating receipts increased

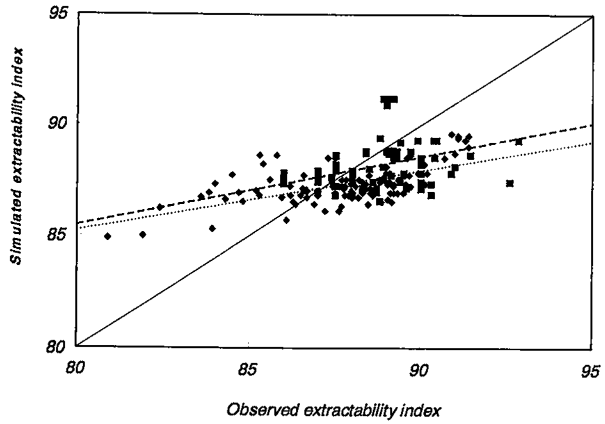
A


Simulated root yield (kg.m^{-2})
Observed root yield (kg.m^{-2})
2
4
6
8
10

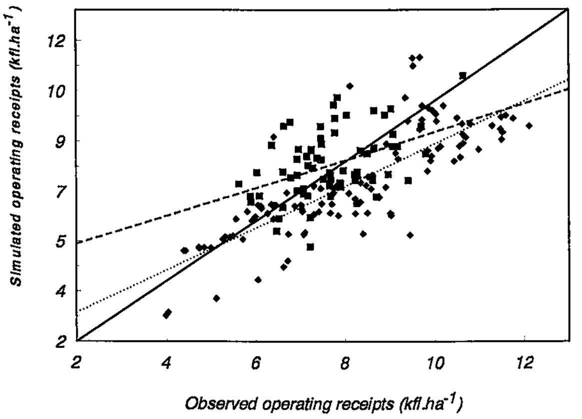
B


Simulated sugar content (%)
Observed sugar content (%)
14
15
16
17
18
19

C


Simulated extractability index
Observed extractability index
80
85
90
95

D



E

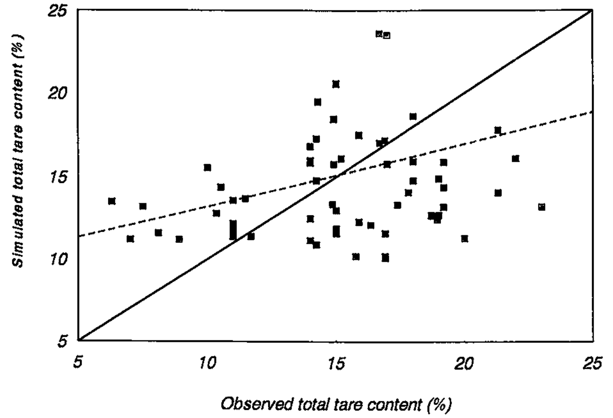
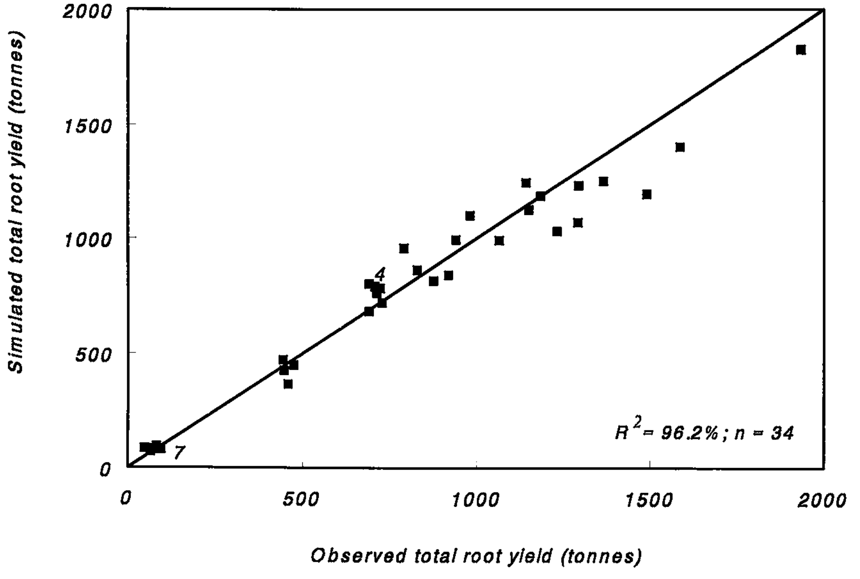
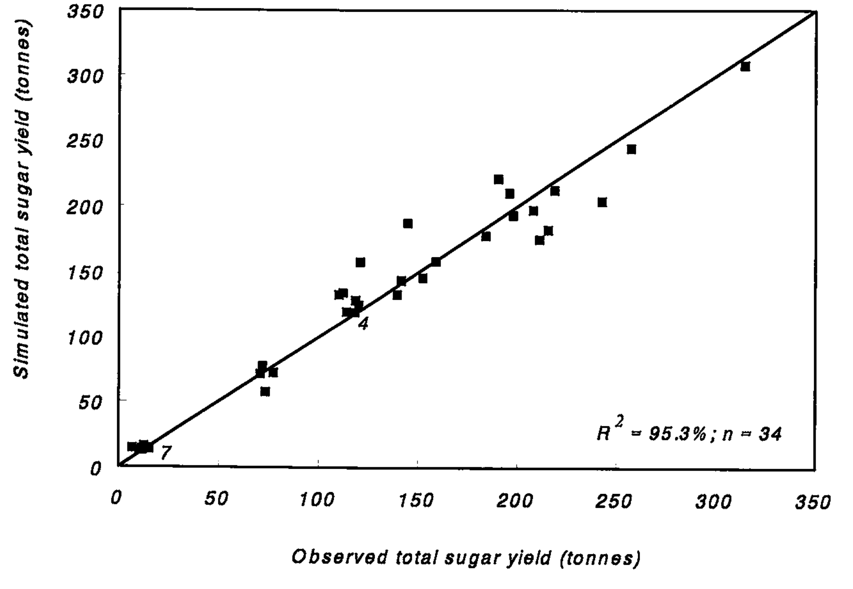


Figure 1 Simulated vs. observed results of 183 individual fields. A: Root yield; B: Sugar content; C: Extractability index; D: Operating receipts; E: Total tare content (■: commercial fields; ◆: experimental fields; __ : Y = X; - - : regression of commercial fields; . . : regression of experimental fields.)

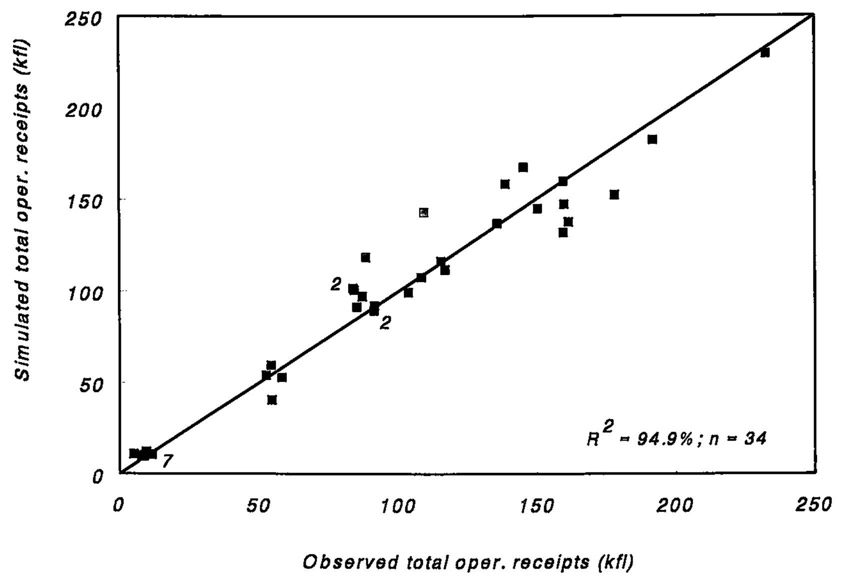
A


2000
1500
1000
500
0
Simulated total root yield (tonnes)
4
7
R 2= 96.2% ; n = 34
0
500
1000
1500
2000
Observed total root yield (tonnes)

B


350
300
250
200
150
100
50
0
Simulated total sugar yield (tonnes)
4
7
R 2 = 95.3% ; n = 34
0
50
100
150
200
250
300
350
Observed total sugar yield (tonnes)

C



D

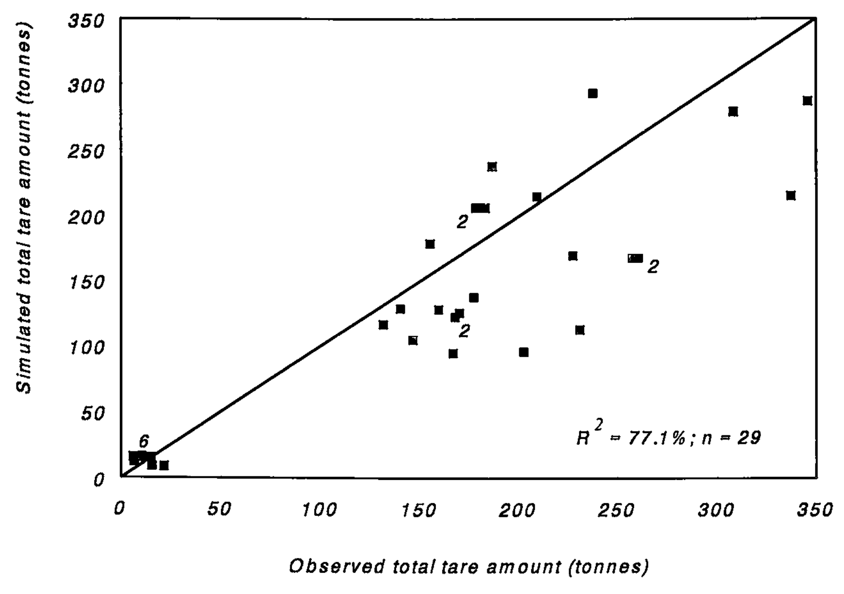
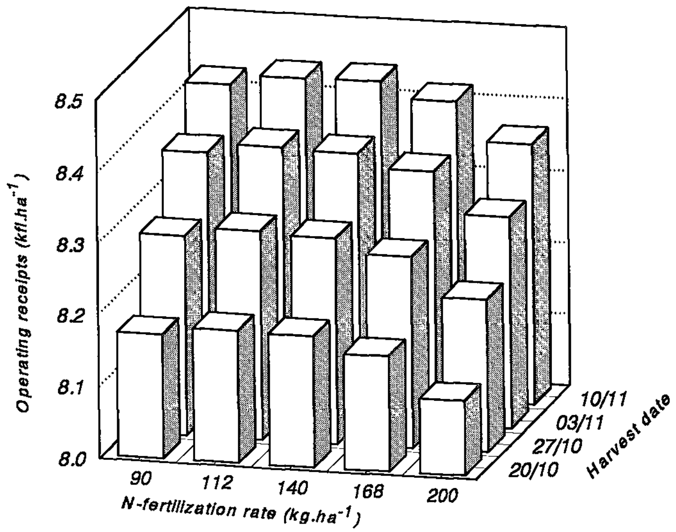


Figure 2 Simulated vs. observed results of 34 farms. A: Total root yield; B: Total sugar yield; C: Total operating receipts; D: Total tare amount; numbers give more than one observation with (more or less) same coordinates (__ : Y = X).

Table 4 Simulated operating receipts for different combinations of plant density, harvest date and N-rate. In the calculations, a sugar quota level of 10 tonnes sugar.ha^{-1} was assumed, beyond which the sugar beet price decreased from 0.115 kfl.ton^{-1} to 0.045 kfl.ton^{-1}.

Plant density (m^{-2})	Harvest date	N-rate (kg.ha^{-1})				
		90	112	140	168	200
7	20/10	7.99	8.01	8.01	7.98	7.92
7	27/10	8.10	8.11	8.11	8.08	8.02
7	03/11	8.18	8.20	8.19	8.17	8.11
7	10/11	8.24	8.26	8.26	8.23	8.17
8	20/10	8.07	8.09	8.08	8.05	8.00
8	27/10	8.17	8.19	8.19	8.16	8.10
8	03/11	8.26	8.28	8.27	8.25	8.19
8	10/11	8.32	8.34	8.34	8.31	8.25
9	20/10	8.14	8.15	8.15	8.12	8.07
9	27/10	8.24	8.26	8.26	8.23	8.17
9	03/11	8.33	8.34	8.34	8.32	8.26
9	10/11	8.39	8.41	8.40	8.39	8.33
10	20/10	8.17	8.18	8.18	8.16	8.10
10	27/10	8.28	8.29	8.29	8.27	8.21
10	03/11	8.36	8.38	8.37	8.35	8.30
10	10/11	8.42	8.44	8.44	8.42	8.36
11	20/10	8.18	8.20	8.19	8.16	8.11
11	27/10	8.28	8.30	8.30	8.27	8.22
11	03/11	8.36	8.39	8.39	8.36	8.30
11	10/11	8.43	8.45	8.45	8.42	8.37
12	20/10	8.16	8.17	8.17	8.15	8.09
12	27/10	8.26	8.28	8.27	8.25	8.20
12	03/11	8.35	8.36	8.36	8.34	8.28
12	10/11	8.41	8.42	8.42	8.40	8.34

A



B

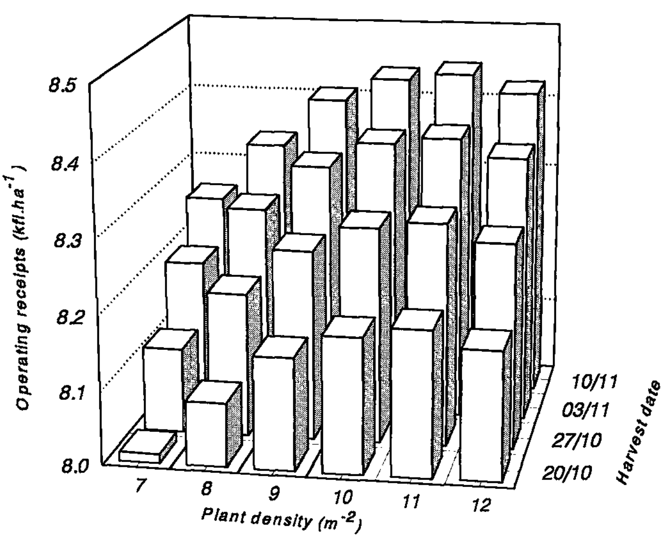


Figure 3. Simulated operating receipts as a function of harvest date and N-fertilization rate (A) and of harvest date and plant density (B). In A, plant density was set at 10 plants.m^{-2}; in B, N-fertilization rate was set at 112 kg.ha^{-1}. Simulation results of a 1995 sugar beet field.

independently of plant density. For all harvest dates, a plant density of 11 plants.m^{-2} gave the best results, but the results with 10 plants.m^{-2} were almost similar.

Table 5 summarizes the results of Table 4 and extends it to the other parameters simulated. It lists the maximum and minimum values for each parameter, resulting from 120 simulation runs. The maximum values for root and sugar yields and sugar content were found with the last harvest date, a plant density of 9 plants.m^{-2}, 10 plants.m^{-2} and 11 plants.m^{-2} respectively and an N-rate of 200 kg.ha^{-1}, 200 kg.ha^{-1} and 90 kg.ha^{-1}, respectively. The maximum operating receipts with quota regulations and adjusted for tare penalties were 7.50 kfl.ha^{-1}, simulated when harvest date, plant density and N-rate were 10 November, 10 plants.m^{-2} and 112 kg.ha^{-1}, respectively. The maximum extractability index was 88.0 when the plant density was 10-12 plants.m^{-2} and the N-rate 90 kg.ha^{-1}. Maximum and minimum amounts of post-harvest residual N in leaves and crowns were 146 kg.ha^{-1} and 112 kg.ha^{-1} for the combinations of 10 November, 11 plants.m^{-2} and 200 kg N.ha^{-1}, and 20 October, 7 plants.m^{-2} and 90 kg N.ha^{-1}, respectively.

The simulated root and sugar yields, sugar, (K + Na), α-amino-N and tare contents and operating receipts (Tables 4 and 5) were much higher than the observed ones, whereas the simulated extractability index was lower than the observed one. The calculated operating receipts with quota regulations and adjusted for dirt penalties ('Pay_{2b}') were 7.74 kfl.ha^{-1}, which was higher than the maximum simulated value in Table 5 (7.50 kfl.ha^{-1}).

Discussion

Test on 183 fields

For a number of parameters, the commercial fields had lower values for variance accounted for than the experimental fields. This was partly caused by smaller ranges of root and sugar yields, α-amino-N content and extractability index for the commercial fields than for the experimental fields (Harrison, 1990). Since commercial fields were organised to produce maximum profit rather than scientific insight, the values of the input parameters such as N-availability and plant density were in general closer to the optimum values than on the experimental fields. As a consequence, both the observed and simulated values had a tendency to centre around their averages, producing a 'cloud' rather than a range of simulated values. Nevertheless, the prediction errors (an important characteristic for a model that is designed for advice to sugar beet growers) were relatively low. Still, a prediction error of 12.5% for operating receipts represents more than 1 kfl.ha^{-1}. For the final version of the decision support system, relative profits or changes relative to certain basic values could be used; the analysis of different scenarios, i.e. combinations of different sowing, harvest and delivery dates, plant densities and N-availabilities, would

Table 5 Maximum and minimum values of different simulated parameters. Different combinations of plant density, harvest date and N-rate were applied, as given in Table 2.

Parameter [1]	Max / min	Value	Harvest date [2]	Plant density (m^{-2})	N-rate ($kg.ha^{-1}$) [2]
Root	Max	7.82	10/11	9	200
Root	Min	6.88	20/10	7	90
Sugar	Max	1.32	10/11	10	200
Sugar	Min	1.17	20/10	7	90
S.cont	Max	17.4	10/11	11	90
S.cont	Min	16.4	20/10	8	200
K + Na	Max	40.5	-	7	200
K + Na	Min	35.1	-	11	90
αN	Max	13.3	-	7	200
αN	Min	8.5	-	11	90
Extr	Max	88.0	-	10-12	90
Extr	Min	86.2	-	7	200
Tare	Max	40.9	-	12	-
Tare	Min	39.0	-	9	-
Pay_{1a}	Max	9.88	10/11	10	168
Pay_{1a}	Min	8.76	20/10	7	90
Pay_{1b}	Max	8.92	10/11	10	140
Pay_{1b}	Min	7.88	20/10	7	90
Penalty	Max	1.04	10/11	12	200
Penalty	Min	0.88	20/10	7	90
Pay_{2a}	Max	8.45	10/11	11	112-140
Pay_{2a}	Min	7.92	20/10	7	200
Pay_{2b}	Max	7.50	10/11	10	112
Pay_{2b}	Min	6.99	20/10	7	200
Nrem	Max	146	10/11	11	200
Nrem	Min	112	20/10	7	90

Notes to Table 5:

[1] Most parameters are described in note 1 of Table 1.

'Pay$_{1a}$'	= Operating receipts without quota regulations	[kfl.ha^{-1}]
'Pay$_{1b}$'	= Operating receipts without quota regulations after adjusting for tare penalties	[kfl.ha^{-1}]
'Penalty'	= Penalty for tare	[kfl.ha^{-1}]
'Pay$_{2a}$'	= Operating receipts with quota regulations	[kfl.ha^{-1}]
'Pay$_{2b}$'	= Operating receipts with quota regulations after adjusting for tare penalties	[kfl.ha^{-1}]
'Nrem'	= Residual N in leaves and crowns after harvest	[kg.ha^{-1}]

[2] '-' indicates that there was no effect of harvest date and/or N-rate on the maximum and/or minimum value of the respective parameter.

then lead to an indication of the optimal combination and give an order of magnitude of the changes in yield, quality, financial returns and post-harvest residual N in leaves and crowns expected, without being focused too much on the absolute values of the predictions.

The relatively low variances accounted for for all parameters of the commercial fields greatly improved when total root and sugar yields, tare amounts and operating receipts per farm were predicted for each year (Table 3). To a large extent, this was caused by the larger ranges of observed and simulated values compared to those in Table 1, whereas the relative prediction errors were only slightly lower. This shows that regression of model outputs on real-system data is not a satisfactory test of the validity of the model.

The results of the test procedure of Mitchell and Sheehy showed that the model could only be accepted as adequate when relatively high limits for prediction error were applied, indicating that the model only allows for rough estimates of yield, quality and financial parameters. For our aim of decision support, PIEteR needs to be improved, especially when absolute results are considered more important than relative ones.

In general, PIEteR resulted into relatively high predicted values with low observed and relatively low values with high observed values of the different parameters, as shown by the regression coefficients in Table 1. This was partly caused by the regression method, which always gives regression intercepts greater than nil and slopes smaller than unity (Aigner, 1972). PIEteR had a certain capacity to adapt for different conditions. This capacity was not complete, yet, so that in general low observed values were overestimated and high observed values were underestimated. This was true for all parameters, both for commercial and for experimental fields. The overestimation of root and sugar yields and operating receipts at low values was smaller for the experimental fields than for the commercial fields, possibly as a result of a more accurate recording of data and of growth-limiting or growth-reducing factors in experiments. The underestimation at high values was more or less the same for commercial and experimental fields. Such trends appeared to be absent for predictions at farm level, except for total tare amount which was more often underpredicted than overpredicted over the full range of observed values.

When the basic version of PIEteR was compared to other models, an F-test was applied, which indicated that the prediction errors for root and sugar yields were not significantly unequal to nil (Smit and Struik, 1995a). In the current version of PIEteR, the prediction errors of all parameters were significantly greater than nil, although for farm results the F-values were lower than for results at field level (values not listed). However, one has to take into account that the test set used by Smit and Struik (1995a) was derived from hand-harvested experiments with 'normal' conditions and four replications whereas in the current test set machine-harvested experimental and commercial fields were analysed, thus greatly improving the risks of unpredictable and variable yield losses. Moreover, the records of the growing conditions and yield parameters of mainly the commercial fields were not complete or sometimes even unrealistic. A validation test could presumably be improved when the grower collected more detailed and accurate information.

Although Smit *et al.* (1995a,b) showed that including plant density and N-availability modules clearly increased the quality of the predictions by PIEteR, in this test the effects were less obvious. When the test was performed without both modules mentioned, the prediction errors for root and sugar yields, extractability index and operating receipts over all commercial and experimental fields increased from 12.2% to 13.6%, from 12.7% to 13.9%, from 1.6% to 2.1% and from 13.2% to 14.8%, respectively, whereas the prediction error for sugar content decreased from 4.5% to 4.3%. The variances accounted for decreased from 52.4% to 47.5%, from 50.9% to 47.7%, from 3.7% to 2.6%, from 31.0% to 8.7% and from 50.3% to 47.6% for root and sugar yields, sugar content, extractability index and operating receipts, respectively.

The variance of the sugar content accounted for was low which partly resulted from low regression coefficients. Sugar content was calculated from the root and sugar yields, which both had certain prediction errors. The prediction errors for root and sugar yields had unequal values or even opposite signs for many fields, causing prediction errors for sugar content which were difficult to explain when sugar content was considered as such. The prediction errors for root and sugar yields were partly due to the use of regional correction factors for their potential levels. Differences for fields compared to the average yields of the region may be different for root and sugar yields. Including historical field or farm specific root yields instead of regional yields as reference values or prediction of potential root and sugar yield levels as functions of soil properties can contribute to the solution of this problem and will improve the prediction of sugar content. The factor 'cultivar' had not been taken into account in this paper. Different cultivars may show different eco-physiological reactions to exogenous factors, and the (absolute) effects may be different for root and sugar yields, depending on cultivar.

Other reasons for errors in sugar content prediction could be regrowth of sugar beet leaves and fibre roots after a period of drought stress and high levels of respiration during warm, cloudy days in autumn. Including these factors in the model would improve its accuracy for sugar content, but would require intensive research. With a root yield of 60 tonnes.ha^{-1}, a beet price of 0.115 kfl.ton^{-1} and a sugar content adjustment of 0.01 kfl.(% sugar content)$^{-1}$ based on a sugar content of 16%, an absolute prediction error of 0.74% for sugar content (Table 1) resulted into a prediction error of 0.44 kfl.ha^{-1} for the operating receipts or 40% of their absolute prediction error. Development of an effective sugar content module would therefore greatly improve the capacity of PIEteR to support growers' decisions.

Decision support

According to the simulation results in Table 4, the grower should have aimed at a harvest date of 10 November, a plant density of 11 plants.m^{-2} and an N-rate of 112 kg.ha^{-1} or 140 kg.ha^{-1} for the field studied. However, the differences with plant densities of 9 plants.m^{-2}, 10 plants.m^{-2} and 12 plants.m^{-2}, and with N-rates of 90 kg.ha^{-1} and 168 kg.ha^{-1} were relatively small. Taking into account the costs of seed and N-fertilizer, the farmer should have aimed at the lowest of the values mentioned, being 9 plants.m^{-2} and 90 kg N.ha^{-1}. The loss in operating receipts compared to the optimum would then be 0.06 kfl.ha^{-1}; the decrease of costs would be about 0.08 kfl.ha^{-1}, resulting from a decrease of about 18% of the seed amount and 22 kg N.ha^{-1}. This also reduces the amount of post-harvest residual N in leaves and crowns to 114 kg.ha^{-1} (not listed). With a plant density of 9 plants.m^{-2}, the tare content would also have been at its minimum.

The differences between the four harvest dates were greater than between the plant densities and N-rates mentioned earlier, stimulating the grower to harvest as late as possible, given certain delivery periods, although risks of frost and harvest problems increase with time (Smit *et al.*, 1996a). However, for regions other than Flevoland, with its fertile soils, the differences between different N-rates and plant densities may be greater; on less fertile soils, a crop is less able to compensate for non-optimal conditions.

Remarkably, the operating receipts with quota regulations and adjusted for tare penalties were maximal with a relatively low N-rate (112 kg.ha^{-1}) compared to the root and sugar yields. The responsible grower had indeed applied the economically optimal amount of N, which in this case was lower than the official recommendations (168 $kg.ha^{-1}$) or those mentioned earlier (140 $kg.ha^{-1}$; Table 2; Smit *et al.*, 1995b).

Compared to the results observed, PIEteR overestimated root and sugar yields, but the simulated operating receipts after adjustment for tare penalties were close to the observed ones, due to a great overestimation of dirt content. Apparently, high *lutum* contents do not always lead to high (dirt) tare contents as the tare module suggests.

Conclusion

Validation of PIEteR showed that predictions of root and sugar yields and financial returns at farm level gave better results than at field level. The prediction errors for the output parameters listed were relatively high, which was partly due to the fact that the data per (commercial) field were not given in sufficient detail. The current version of PIEteR makes decision support possible, but relative values for root and sugar yields, internal and external quality, operating receipts and remaining N in crop residues may be better as output parameters than absolute values.

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References

Aigner, D.J., 1972. A note on the verification of computer simulation models. *Management Science* **18**, 615-619.

Beek, van der, M.A. & P. Wilting, 1994. Onderzoek naar de mogelijkheden van stikstofrijen-toediening bij suikerbieten in 1990-1992. Lelystad, PAGV, Verslag nr. 167, 58 pp.

Floot, H.W.G., J.G. Lamers & W. van den Berg, 1992. De invloed van de intensiteit van het bouwplan op pootaardappelen, suikerbieten en wintertarwe (vruchtwisselingproefveld FH 82). Lelystad, PAGV, Verslag nr. 139, 127 pp.

Geijn, van, N.J., L.C. Giljam & L.H. de Nie, 1983. α-amino-nitrogen in sugar processing. In: Proceedings IIRB-symposium "Nitrogen and sugar-beet", 16-17 February 1983. Brussels, IIRB: 13-24.

Harrison, S.R., 1990. Regression of a model on real-system output: an invalid test of model validity. *Agricultural Systems* **34**, 183-190.

Menu, W.J.L., 1993. Wijziging kwaliteitsbetaling suikerbieten. *Maandblad Suiker Unie* **27**, 11, 6-7.

Mitchell, P.L. & J.E. Sheehy, 1996. Comparison of predictions and observations to assess model performance: a method of empirical validation. In: Kropff, M.J. *et al.* (eds). Applications of system approaches at the field level. Proceedings of the second symposium on system approaches for agricultural development (SAAD2), IRRI, December 1995. Kluwer, Dordrecht, The Netherlands (in press).

Smit, A.B. & P.C. Struik, 1995a. The first step towards a decision support system for sugar beet growing: selection of a basic model. *Journal of Agronomy and Crop Science* **175**, 213-220.

Smit, A.B. & P.C. Struik, 1995b. PIEteR: a field-specific production model for sugar beet growing. *Journal of Agronomy and Crop Science* **175**, 335-348.

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1995a. Modelling the influence of plant density on yield, sugar content and extractability of sugar beet. In: Proceedings of the 58th IIRB-congress, 19-22 June 1995, France. Brussels, IIRB: 413-424.

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1995b. Nitrogen effects in sugar beet growing. A module for decision support. *Netherlands Journal of Agricultural Science* **43**, 4, 391-408.

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1996a. Prediction of various effects of harvest date in sugar beet growing. *Journal of Agricultural Engineering Research* (submitted).

Smit, A.B., P.C. Struik, J.H. van Niejenhuis & J.A. Renkema, 1996b. Critical plant densities for resowing. *Journal of Agronomy and Crop Science* (in press).

CHAPTER 10

A farm economic module for tactical decisions on sugar beet area

A.B. Smit, J.H. van Niejenhuis and J.A. Renkema

Abstract

For decisions at operational level in sugar beet growing (for example on plant density, nitrogen fertilizer rate and harvest date), returns above allocated variable costs can be used as a criterion for comparing the economics of different options. For (tactical) decisions on sugar beet area, the sugar beet grower has to take into account the opportunity costs of labour and equipment. Our calculations are based on the assumption that these can be reflected by the respective allocated fixed costs. In this paper, a method of allocating fixed costs to crops in the cropping plan is described and included in PIEteR, a bio-economic model for sugar beet growing. Seed and ware potato and sugar beet had the highest returns above allocated variable costs, but when allocated fixed costs were also taken into account, sugar beet appeared to be more profitable than seed potato.

When sugar quota were included in our calculations, the returns above allocated variable and fixed costs decreased with sugar yields beyond quota level, because prices of C-beets are lower than those of quota-beets. Growing C-sugar beet was not attractive; wheat growing was more profitable. However, the estimated area required to grow the exact amount of quota-sugar was uncertain with a standard deviation of ± 10%.

Keywords: *Beta vulgaris*, decision support, gross margin, profit, simulation model, sugar beet

Introduction

The production model PIEteR [1] has been developed as a basis for a field specific decision support system in sugar beet (*Beta vulgaris* L.) growing in The Netherlands. It focuses on

[1] PIEteR means: 'Production model for sugar beet, including Interactions between Environment and growing decisions, and their influence on the quantitative, qualitative and financial Result'.

grower's decisions at semi-operational and operational level. The main decisions at semi-operational level are those on N-fertilization and plant density, which have to be taken before sowing (Smit *et al.*, 1995b,a). The decisions at operational level which can be supported by PIEteR, are those on resowing, which have to be taken one month after sowing, and on harvest and delivery dates, to be taken from the beginning of August and onwards (Smit *et al.*, 1996c,b). The model predicts root and sugar yields, from which sugar content is calculated, (K + Na) and α-amino-N contents, from which the extractability index is calculated, and the operating receipts [2], which are calculated from the yield and quality parameters (Smit and Struik, 1995; Smit *et al.*, 1995a). The model predicts the parameters listed for every day during the growing season, using historical weather data until the day of simulation and average weather data afterwards (Smit *et al.*, 1996b). The simulated rates of crop development until canopy closure and of root and sugar production afterwards are corrected for suboptimal soil moisture contents.

So far, we have focused on decisions at operational and semi-operational level. In this paper, we study the decision on the area of sugar beet at a tactical level. Quota regulations restrict the amount of sugar beet which can be delivered for the full quota price. When the deliveries are smaller than the quota over a number of years, the quota will be reduced. The opposite is not true: when the deliveries are larger than the quota over a number of years, the quota will not be enlarged. The grower will generally try to avoid reduction of the quota, since sugar beet is one of the most profitable crops in Dutch arable farming. Therefore, he will tend to minimize the risk of producing an amount of sugar below his quota; as a result of this, he decides to grow an area of sugar beet that is larger than necessary to produce his quota when average root and sugar yields over a number of years are considered. However, it is questionable whether this is a good decision. A module has been developed and included in PIEteR to compare the marginal returns and the costs of an increase of the area by 1 ha.

In addition, decisions on the amount of sugar beet that the grower intends to deliver, can be taken at (semi-)operational and strategic levels:

1) at (semi-)operational level; a delay in harvest date generally leads to a higher yield. Land, equipment, labour force and cropping plan, including sugar beet, are considered as fixed. With later harvest, the operating receipts of the extra yield decreases and the risks of high dirt tare contents, severe soil structure damage and others increase (cf. Smit *et al.*,

[2] Defined as the amount of money that the farmer receives after delivering his beets, corrected for internal quality (sugar content and extractability index according to Van Geijn *et al.* (1983)).

1996b). The optimal harvest date is calculated as the day that marginal returns resulting from this decision equal marginal costs.
2) at strategic level; the grower must decide on farm size and long term farm organisation (crop rotation, percentage of the crops that are labour intensive, fixed labour force), including the position of sugar beet in the crop rotation and the purchase of land with or without sugar quota and of equipment for sugar beet growing; farm area and farm organisation are not considered as being fixed, so that all costs of land, equipment and (fixed) labour must be taken into account, based on their replacement values.

For tactical decisions on the area of sugar beet in the cropping plan for the next year, on which we focus in this paper, one must consider total farm area and organisation, including fixed labour and equipment as being fixed. Often, linear programming (l.p.) is used to assess the most profitable cropping plan and, optionally, the required equipment. In our case, PIEteR is used because of its field specific character, so that variation in the output parameters listed and in weather conditions are taken into account. Farms and fields vary to a large extent because of differences in soil type and quality, resulting in differences in susceptibility for drought stress and different optimal sowing and harvest dates and nitrogen fertilization rates. Although the l.p. technique has the advantage that many activities and restrictions can be included in the analysis simultaneously and opportunity costs are calculated for limiting production factors as land, labour and equipment, including the variations listed would make the l.p. model too complex to oversee and handle.

Unlike a linear programming model, PIEteR does not calculate opportunity costs for equipment and labour, so that these have to be estimated differently. Therefore, two possibilities are considered: 1) The opportunity costs equal nil; equipment and labour are not limiting and cannot be used differently. When the opportunity costs equal nil, we take the returns above allocated variable costs as a measure for planning; 2) The opportunity costs are positive; labour and equipment are limiting and there are alternative ways to use them. The opportunity costs can be so high that an increase of the capacity, purchase of land (with quota) and equipment, and an increase of the fixed labour force, are profitable. This level of opportunity costs is more or less the upper level of the opportunity costs [3]. When an increase of capacity and labour is profitable, the opportunity costs can be reflected by the allocated fixed costs of labour and equipment, based on replacement values. Most farms will have opportunity costs in between nil and the upper level mentioned. In our calculations in this paper both upper and lower limit are taken into account.

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[3] In some cases, the upper level of opportunity costs may be even higher since equipment and labour are mostly to be obtained in full units. An alternative would be to utilize residual capacities on other farms.

With increasing sugar beet area, both the operating receipts of an extra ha of sugar beet, mainly with sugar yields beyond the quota level, and the allocated fixed costs decrease. Different options of land use with given total farm area, equipment and (fixed) labour are compared on the basis of returns above allocated variable and/or fixed costs.

Materials and methods

Different definitions of returns can be used. In arable farming, the term 'returns above operating costs' is often used; it results when the allocated operating or variable costs are subtracted from the total revenues or operating receipts. The revenues should include all cash and non-cash revenues. The variable costs contain: seed; fertilizers; chemicals; crop insurance; interest; and tare penalties (Kay and Edwards, 1994; Roeterdink and Haaksma, 1993). The variable costs are a good measure for operational decision making, since long-term factors such as costs of machinery and land are not taken into account (Roeterdink and Haaksma, 1993).

The parameter 'returns to management' is calculated by subtracting total costs from total revenues or, which is the same, the total ownership costs from the total returns above operating costs (Kay and Edwards, 1994) and it is suitable for evaluation at strategic level. In our calculations, intended for support of tactical decision making, we applied another term: 'returns above allocated variable and fixed costs', shortly 'returns' (Equation 1), which does not include costs of land. 'Fixed costs' are here defined as the total operation costs or the costs of labour, equipment and contract work, which is different from the normal definition.

$$returns = oper.rec. - (var.costs + calc.fixed\,costs) \tag{1}$$

in which:

returns	=	returns above allocated variable and fixed costs	[kfl.ha^{-1}]
oper. rec.	=	operating receipts	[kfl.ha^{-1}]
var. costs	=	allocated variable costs	[kfl.ha^{-1}]
calc. fixed costs	=	allocated fixed costs	[kfl.ha^{-1}]

Equation 1 gives the contribution of a crop to the total returns of a farm, taking into account the organisation of the farm (crop rotation, percentage of the crops that is labour intensive, fixed labour force), including farm equipment and cropping plan, since the allocated calculated fixed costs greatly depend on the combined use of the available machinery for the different crops. Contractors' costs are not included in the term 'fixed costs', but because we wanted to discuss costs of labour, equipment and contractors as a group, they are listed under fixed costs in this paper.

A module of PIEteR was developed to include the economic aspects of other crops than sugar beet, to calculate costs of machinery, labour and contractors per crop and in total, and to compare returns above allocated variable and fixed farm costs. The crops included were ware, seed and starch potato, sugar beet, winter and spring wheat, spring barley and pea. The method of cost allocation applied has been described by Van Niejenhuis (1981).

We defined a standard equipment for arable farms, not including equipment for storage of products (Table 1). For each machine, except for tractors and transportation, the number of treatments per crop was estimated, multiplied by the areas of the respective crops. The total costs of each machine were divided by the total treated area, resulting into the average costs per ha treated. By multiplying the average costs per machine by the number of treatments for a crop, the allocated costs of the machine for a hectare of the crop were obtained. For tractors and transportation the same procedure was applied, but total costs were not allocated to area treated but to working hours.

Table 1 Standard equipment for arable farms, not including equipment for storage.

Type	Capacity (kW, tonnes, m, l)	Replacement value (kfl)
Tractor 1	35 kW	65
Tractor 2	70 kW	110
Transportation	8 tonnes	23.6
Plough	1.2 m	18.8
Fertilizer spreader	18 m, 1500 l	8.0
Power harrow	3 m	16.7
Potato planter	3 m	25
Row rotary cultivator	3 m	24.2
Chemical sprayer	21 m	27.2
Chemical sprayer for row application	3 m	2.3
Harrow for weed control	3 m	10

The costs of each machine consisted of two major posts: 1) depreciation, interest, maintenance and insurance; 2) costs of depot. The first post contained a fixed percentage for each machine multiplied by its replacement value. The second post contained the required area in the machine depot per machine, including 40% for walking, etc.

The total costs of machinery per ha of each crop were calculated as the sum of the required treatment costs; contractors' costs (standard tariffs from Roeterdink and Haaksma (1993)) and allocated labour hours (from Roeterdink and Haaksma (1993)) were added to calculate the total fixed treatment costs. The allocated labour hours consisted of the respective use of both tractors and the time for hand labour. General and management activities, like book keeping, delivery of products outside the farm, cleaning, etc., were not included.

The returns of the different crops were calculated as the multiplication of observed yields from the basic data of Wijnands *et al.* (1995) of the main products and their standard prices; for the latter and for additional minor products, standard values from Roeterdink and Haaksma (1993) were applied. By subtracting standard values for allocated variable costs from the same source, the returns above allocated variable costs were obtained. The returns above allocated variable and fixed costs were calculated by subtracting the costs of labour, equipment and contract work from the returns above allocated variable costs. Standard working hours for treatments and hand labour, prices of labour and standard costs of contract work were also derived from Roeterdink and Haaksma (1993).

We ran the model for 16 combinations of farm and year as described in Table 3 (with data on soil type(s), cropping plan and observed yield and quality parameters of the crops in the year studied), which had been randomly selected from the basic data of Wijnands *et al.* (1995), part of which had also been tested in Smit *et al.* (1996b). The data covered different regions in The Netherlands during the years 1991 - 1993. Other crops than listed and set-aside were not included in the module.

To examine the effect of sugar quota, we assumed that 2500 kg.(ha total arable land)$^{-1}$ [4] could be delivered for a price of 0.115 kfl.(ton beet)$^{-1}$ with a sugar content of 16% and an extractability index of 85 (Menu, 1993; cf. Table 2, foot note 5); for beet above quota, a sugar beet price of 0.045 kfl.ha^{-1} was assumed (Smit *et al.*, 1996b). Returns for C-sugar beet growing were calculated by giving the quota of each farm value 0. With given allocated variable and fixed costs of sugar beet growing and simulated root yields, a limit price was calculated for which the returns above allocated variable and fixed costs for sugar beet growing were equal to nil.

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[4] Including set-aside and area of crops which had not been included in the module.

Results

Table 2 gives the results of calculations for 16 combinations of farm and year (with data on soil type(s), cropping plan and observed yield and quality parameters of the crops in the year studied). The returns per crop above allocated variable costs were very different per combination of farm and year. On average, seed potato had the highest returns, 8 kfl.ha^{-1}, and starch potato and pea the lowest, about 1.7 kfl.ha^{-1}. The average costs of labour, equipment and contractors varied between 1.1 kfl.ha^{-1} and 4.2 kfl.ha^{-1} for spring wheat and ware potato, respectively. The average returns above allocated variable and fixed costs were highest for seed potato, 4.3 kfl.ha^{-1}, and almost nil or even negative for wheat, spring barley and pea, and starch potato, respectively. The simulated returns for sugar beet were much higher than the observed ones.

When sugar quota of 2500 kg.ha^{-1} and a sugar beet price above quota of 0.045 kfl.ton^{-1} were assumed, the average returns above allocated variable costs of sugar beet, based on simulated yields for the different combinations of fields and years, decreased from 6.64 kfl.ha^{-1} to 6.21 kfl.ha^{-1}. The returns above allocated fixed costs for the same yields decreased from 2.87 kfl.ha^{-1} to 2.44 kfl.ha^{-1}. The sugar quota of ten farms were not exceeded.

When all sugar quota were set to nil, the returns above allocated variable costs and those above allocated fixed costs were 1.33 kfl.ha^{-1} and - 2.45 kfl.ha^{-1}, respectively (Table 2, footnote 6). Table 3 gives the simulated root yields, the allocated variable and fixed costs and the prices of C-beet for which the returns above allocated variable and fixed costs were equal to nil for all farms included. The limit price varied between 0.063 kfl.ton^{-1} for farms C, J (in 1992) and L, and 0.128 kfl.ha^{-1} for farm H.

Discussion

Five of the farms (D - H in Table 3) were located on North-eastern sandy and reclaimed peat soils and had observed returns above allocated variable costs for sugar beet in 1991 of 2.99 kfl.ha^{-1} (value not listed). Cuperus (1989) calculated these in a normative way as 3.28 kfl.ha^{-1}. The observed yields for the farms in this area were lower than the simulated ones: 41.4 tonnes.ha^{-1} and 50.8 tonnes.ha^{-1}, respectively. Yield potential of the fields simulated was probably lower than the average regional one. This problem could be solved by including historical field or farm levels for root and sugar yield (Smit *et al.*, 1996a). However, we did not have the information required. Moreover, the number of observations was too small for detailed conclusions. For demonstration purposes, we based our calculations and the decision making on the simulated yields, costs and returns instead of the observed ones. For the other crops, observed yields were used in the calculations.

The returns above allocated variable costs were highest for seed and ware potato and

Table 2 Returns above allocated variable costs, fixed costs and returns above allocated fixed costs; average values of 16 farm/year combinations, with observed and simulated yields and prices of sugar beet, respectively.

Crop	Number of farms	Returns [1] (kfl.ha^{-1}, kfl)	Fixed costs [2] (kfl.ha^{-1}, kfl)	Returns [3] (kfl.ha^{-1}, kfl)
Ware potato	4	5.35	4.23	1.12
Seed potato	11	7.96	3.69	4.27
Starch potato	8	1.70	3.18	- 1.48
Sugar beet_obs [4]	16	5.11	3.77	1.34
Sugar beet_sim [5]	16	6.64	3.77	2.87
Sugar beet_sim [6]	16	6.21	3.77	2.44
Winter wheat	11	1.81	1.62	0.185
Spring wheat	2	1.27	1.12	0.077
Spring barley	9	2.48	1.21	1.27
Pea	5	1.72	1.58	0.140
Total cropping plan [4,7]	16	163	117	52.5
Total cropping plan [5,7]	16	185	117	71.6
Total cropping plan [6,7]	16	183	117	66.3

[1] Returns above allocated variable costs.

[2] Allocated costs of labour, equipment and contractors.

[3] Returns above allocated variable costs and allocated costs of labour, equipment and contractors.

[4] Observed sugar beet yields and average sugar beet prices were used (the latter from Roeterdink and Haaksma, 1993).

[5] Simulated sugar beet yields and sugar beet prices were used. Sales system: 0.115 kfl (1 kfl = 1000 Dutch guilders) per net ton of sugar beet, corrected with 9% per percent sugar content above or under 16% and with 0.9% per point extractability index above or under 85; penalties for dirt tare were not included in our calculations. This system was used in 1993 by Suiker Unie, one of the sugar beet processing companies in the Netherlands (Menu, 1993).

[6] As [5], but with the following assumptions:

a a sugar quota of 2500 kg.(ha total arable land)$^{-1}$;

b a sugar beet price above quota of 0.045 kfl.ton^{-1}.

Additional results (average values of 16 farm/year combinations):

Estimated sugar quota	=	135 tonnes
Amount of C-sugar	=	11.0 tonnes
Operating receipts quota part	=	7.54 kfl.ha^{-1}
Operating receipts non-quota part	=	0.23 kfl.ha^{-1}.

Ten farms did not produce C-sugar.
The average returns above allocated variable costs and the returns above allocated variable and fixed costs (not including costs of land) of C-sugar beet growing were 1.33 $kfl.ha^{-1}$ and - 2.45 $kfl.ha^{-1}$, respectively. When costs of equipment were not taken into account, allocated fixed costs were 2.08 $kfl.ha^{-1}$ and the returns above allocated variable and fixed costs - 0.75 $kfl.ha^{-1}$.

[7] Average total values per farm.

sugar beet (Table 2). Jager (1995b) mentioned average values of 10.1 $kfl.ha^{-1}$, 6.75 $kfl.ha^{-1}$ and 5.94 $kfl.ha^{-1}$ for the three crops respectively for all arable farms (on clay soils in the case of seed potato) in 1989 - 1993. In our calculations, seed potato growing on other than clay soils played a role. Jager's values for sugar beet were in between the observed and simulated results in Table 2.

The returns above allocated fixed costs of sugar beet were higher than those for ware potato (Table 2). In general, Dutch arable farmers try to maximize the area of (seed and/or ware) potato and sugar beet, which is in agreement with the profitability indications given in Table 2. The respective areas are limited by maxima for cropping intensity and/or by sugar quota. The last limitation is not a very rigid one, however. When a farmer delivers more sugar beet than his quota allows, he will have a problem with profitability. When he delivers less than his quota, each year, he will loose part of his quota in the end. Therefore, more insight into the risk that the production exceeds the quota is needed to take balanced decisions on the area of sugar beet to grow.

For the 16 combinations in general, an increase of the area of sugar beet with 1 ha increased the total profit by 2.87 kfl, not taking into account costs of land and the (small) decrease of allocated fixed costs through the increased total farm area (Table 2). However, with total farm area fixed, sugar beet had to replace another crop, most likely winter wheat. Therefore, the returns above allocated variable costs and allocated costs of labour, equipment and contractors of 1 ha of winter wheat, 0.185 kfl, had to be subtracted from the extra profit of 1 additional ha of sugar beet, so that an extra net profit of 2.69 kfl remained. This calculation was only valid below the quota limits.

Beyond the quota limits, the situation was totally different. The average returns above allocated variable costs of 1 ha of C-beet were of the same order of magnitude as those of spring wheat, but when fixed costs were also taken into account the returns were negative, even when costs of equipment (1.69 $kfl.ha^{-1}$) were not taken into account (Table 2, footnote 6). Thus, growing 1 ha more than necessary to deliver the grower's quota was not profitable. With very high prices for C-beet, this could be different. The minimal price at which C-beet growing is profitable depended largely on the yield level, but also on the fixed costs (Table 3). With the simulated root yields listed, which were on average higher than the observed ones, the C-price had to be at least 0.063 $kfl.ton^{-1}$ to make C-beet

Table 3 Simulated root yields and operating receipts; standard allocated variable costs; fixed costs (labour, equipment and contractors); returns above allocated variable and fixed costs when sugar quota = 0; and limit price for C-beets when the returns above allocated variable and fixed costs = 0. Values of 16 combinations of farm and year.

Farm nr [1]	Root yield (tonnes.ha^{-1})	Operating receipts [2] (kfl.ha^{-1})	Variable costs [3] (kfl.ha^{-1})	Fixed costs [4] (kfl.ha^{-1})	Returns [5] (kfl.ha^{-1})	Limit price C-beet [6] (kfl.ton^{-1})
A-1993	74.7	9.85	1.65	4.93	- 3.21	0.088
A-1992	66.4	8.27	1.65	5.14	- 3.81	0.102
B-1992	64.2	7.37	1.65	3.42	- 2.18	0.079
C-1992	73.5	9.86	1.65	2.95	- 1.29	0.063
D-1991	47.8	6.27	1.73	3.82	- 3.40	0.116
E-1991	54.0	6.81	1.73	3.86	- 3.16	0.104
F-1991	48.2	6.31	1.73	3.22	- 2.77	0.103
G-1991	53.4	7.02	1.73	3.00	- 2.32	0.089
H-1991	50.7	6.22	1.73	4.77	- 4.22	0.128
I-1992	83.7	11.06	1.36	3.92	- 1.51	0.063
I-1991	67.8	8.60	1.36	3.84	- 2.15	0.077
J-1992	70.5	9.16	1.36	3.08	- 1.27	0.063
J-1991	51.2	5.77	1.36	3.00	- 2.05	0.085
K-1992	71.8	9.37	1.36	3.90	- 2.02	0.073
K-1991	65.1	8.31	1.36	3.86	- 2.28	0.080
L-1992	84.1	10.87	1.61	3.67	- 1.49	0.063

1 Code of a farm (A-L) and the relevant year (1991 - 1993).

2 Operating receipts, not corrected for tare content.

3 Allocated variable costs, according to Roeterdink and Haaksma (1993); differences are due to differences in region.

4 Allocated costs of labour, equipment and contractors.

5 Returns above allocated variable and fixed costs with a price of C-beet of 0.045 kfl.ton^{-1}.

6 The price of C-beet to make the returns above allocated variable and allocated fixed costs equal to nil.

growing profitable. This is not often the case (H.C. Antonissen, CSM Sugar, pers. comm., 1995) and even then growing winter wheat or spring barley would often be more profitable in terms of returns above allocated variable and fixed costs (Table 2).

For direct profit, growing of C-beet would not be profitable, according to our calculations. In winter time, when the seed is ordered, it is hard to foresee what the root yield and sugar content will be in the next season. Smit *et al.* (1996b) showed that on April 12th (the average sowing date in The Netherlands), there is a probability of 68%, that the sugar yield will be in the range [average - standard deviation, average + standard deviation] and that the standard deviation is 9.2%; we assumed that this value is also valid for other regions than Wageningen. When a sugar beet area of 10 ha with 'average' yields over a series of years is required to deliver an amount of sugar equal to the quota, an area of 9 - 11 ha would be sufficient in practice, i.e. in 68% of the years, the sugar quota can be produced with an area of 9 - 11 ha. Similarly, in 99.7% of the years, an area of 8 - 12 ha is required.

When the grower decides to sow 11 ha of sugar beet, whereas 10 ha appears to be sufficient, then the loss is 7.31 kfl, the difference between the operating receipts for the quota and non-quota parts of 1 ha sugar beet (Table 2, footnote, 6). Assuming that the grower decides to sow 9 ha of sugar beet, whereas 10 ha appears to be required, and this process repeats itself year after year, then the sugar quota will decrease by the sugar yield of 1 ha. In the long run, 1 ha of sugar beet has then to be replaced by winter wheat, most likely [5], which results in a loss of 4.83 kfl, being the difference between the returns above variable costs of 1 ha quota beets and 1 ha of winter wheat (Table 2). The first loss is larger than the second one, but the first is incidental and the second structural.

When the growing season proceeds, PIEteR could help to calculate the (expected) day of exceeding the sugar quota, taking this estimate into account in decisions on delivery and (mainly) harvest dates (Smit *et al.*, 1996b).

Costs of equipment were based on replacement values, being the value that a grower pays when the same machine is re-purchased, including the technical progress that has been made since the old one was bought. These costs represent more or less the upper limit of the opportunity costs. In practice, a lot of growers on smaller farms work with second-hand equipment and/or base their decisions on salvage values, resulting in lower opportunity costs. On the other hand, the equipment listed (Table 1) is a very sober standard equipment; in practice one may expect a larger equipment. Moreover, buildings and equipment for storage of (mainly harvested) products had not been taken into account, which would affect mainly the costs of potato growing. We calculated average costs of labour, equip-

[5] This is true, when the decision is taken in the autumn before; when the decision is taken near sowing date, spring wheat or spring barley have to be considered as alternative crops. In that case, the loss will be 5.37 kfl and 4.16 kfl, respectively.

ment and contractors of 2.91 $kfl.ha^{-1}$ over all farms and all crops, whereas Jager (1995a) calculated 3.63 $kfl.ha^{-1}$ on average for larger arable farms [6] in 1985/1986 - 1990/1991. However, he included farms with vegetable and/or bulb flower growing in the open field in his calculations, which require a lot of labour.

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References

Cuperus, S., 1989. Bedrijfseconomische perspectieven van akkerbouwbedrijven in de Veenkoloniën. Lelystad, PAGV, Verslag nr. 92, 80 pp.

Geijn, van, N.J., L.C. Giljam & L.H. De Nie, 1983. α-Amino-nitrogen in sugar processing. In: Proceedings IIRB-symposium "Nitrogen and sugar-beet", 16-17 February 1983. Brussels, IIRB: 13-24.

Jager, J.H., 1995a. Akkerbouw 1975-1995. Den Haag, LEI-DLO, Periodieke Rapportage 5-93, 140 pp.

Jager, J.H., 1995b. Saldi van akkerbouwgewassen. Den Haag, LEI-DLO, Periodieke Rapportage 10-93, 129 pp.

Kay, R.D. & W.M. Edwards, 1994. Farm management. New York, McGraw-Hill, Third edition, 458 pp.

Menu, W.J.L., 1993. Wijziging kwaliteitsbetaling suikerbieten. *Maandblad Suiker Unie* **27**, 6-7.

Niejenhuis, van, J.H., 1981. Bedrijfseconomische aspecten van intensieve horizontale samenwerkingsvormen op akkerbouwbedrijven. Wageningen, WAU, PhD-thesis, 171 pp. Separate appendices, 25 pp.

Roeterdink, H.W. & J.J. Haaksma, 1993. Kwantitatieve informatie voor de akkerbouw en de groenteteelt in de vollegrond. Bedrijfssythese 1993-1994. Lelystad, IKC-AGV & PAGV, publikatie nr. 69, 204 pp.

Smit, A.B. & P.C. Struik, 1995. PIEteR: a field-specific production model for sugar beet growing. *Journal of Agronomy and Crop Science* **175**, 335-348.

[6] According to definitions of the Agricultural Economics Research Institute (LEI-DLO), larger farms have a size of about 40 dsu (Dutch Size Units) or more (Jager, 1995a).

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1995a. Modelling the influence of plant density on yield, sugar content and extractability of sugar beet. In: Proceedings of the 58th IIRB-congress, 19-22 June 1995, France. Brussels, IIRB: 413-424.

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1995b. Nitrogen effects in sugar beet growing. A module for decision support. *Netherlands Journal of Agricultural Science* **43**, 4, 391-408.

Smit, A.B., G.J.W. Muijs, P.C. Struik & J.H. van Niejenhuis, 1996a. Evaluation of a model for sugar beet production by comparing field measurements with computer predictions. *Computers and Electronics in Agriculture* (accepted).

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1996b. Prediction of various effects of harvest date in sugar beet growing. *Journal of Agricultural Engineering Research* (submitted).

Smit, A.B., P.C. Struik, J.H. van Niejenhuis & J.A. Renkema, 1996c. Critical plant densities for resowing. *Journal of Agronomy and Crop Science* (in press).

Wijnands, F.G., P. van Asperen, G.J.M. van Dongen, S.R.M. Janssens, J.J. Schröder & K.B. van Bon, 1995. Innovatiebedrijven geïntegreerde akkerbouw. Beknopt overzicht technische en economische resultaten. Lelystad, PAGV, Verslag nr. 196, 126 pp.

CHAPTER 11

Final discussion

11.1 Introduction

In this thesis, the development of a field specific bio-economic production model for sugar beet growing has been described. After an introduction to the goals that were set for the project and the elements of the total system that would receive attention (Chapters 1 and 2), a basic growth model, PIEteR, is selected (Chapter 3). Chapter 4 describes a number of improvements and extensions to the basic version of PIEteR. In the next chapters, modules for internal quality and plant density (5 and 6), nitrogen husbandry (7), and tare content and harvest date (8) have been developed. Chapter 9 gives the validation and evaluation of the current version of PIEteR at field level. Decisions on sugar beet area are the main topic of Chapter 10.

In this general discussion (Chapter 11), the total project and its products are evaluated, and the potential for applications and improvements is given. In Section 11.2, the results of the model are compared with the goals that were set in Chapters 1 and 2. Section 11.3 deals with the application of the current knowledge as included in PIEteR and Section 11.4 gives an overview of possible strategies to extend PIEteR for other than 'normal' conditions. The chapter ends with a number of conclusions (11.5).

11.2 Evaluation

In this section, the results of the project are compared with the goals that were set at the beginning.

The first goal was to develop a growth model for sugar beet as required for decision support. Smit and Struik (1995a) described the first step, the selection of the prototype of PIEteR as a basic growth model. This choice implied that further development was not approached in a mechanistic but in a descriptive way. As a second step, the effects of soil and weather conditions were included in PIEteR by an improved module, so that the model could be used for every field in The Netherlands when regional or field specific yield and quality data were available for a number of recent years. A module was included to calculate average daily temperatures from maximum and minimum temperatures. The simulation of the days of emergence and of onset of sugar accumulation were improved, and leaf-stages were included as output parameters (Smit and Struik, 1995b). The third step was to extend the output of the model to sugar, (K + Na) and α-amino-N contents, extractability index, amount of crown and dirt tare, operating receipts [1] and returns, and residual nitrogen in crop residues. In Smit *et al.* (1995a,b), it is described how this step was taken.

The second goal was to analyse and quantify the effects of different levels of nitrogen availability, of plant density and of harvest date on the output parameters. These effects were analysed, quantified and included into PIEteR.

The third goal was to develop ideas on how the relationships derived could be integrated into a decision support system (DSS) for sugar beet growing in general and specifically at field level. Integration of the modules of PIEteR in a DSS is described in Smit *et al.* (1996a,c).

This brief overview indicates that every goal was met. However, the prediction errors were relatively large for some of the parameters simulated (Smit *et al.*, 1996a). PIEteR has been developed for average potential yield and quality levels, and effects of cultivars, management skills [2] and other factors have not been taken into account. Decisions on N-availability, plant density and harvest date can be taken simultaneously but also independently, given fixed levels of the other parameters.

11.3 Application of the model

The development of PIEteR has brought scientific progress; the knowledge of different aspects of sugar beet growing has been brought together and summarized in the concised format of a decision support system, which can easily be used and applied. During the process, new research problems have been identified, since not all quantitative information required appeared to be available or sufficiently reliable.

The methodology used is descriptive, applying causal regression analysis on (mostly) experimental field data at crop level. Model calibration and validation were both based on data at crop and field level, whereas very detailed mechanistic models are often calibrated at a lower level, viz. organ or plant level. The results give an indication, but not a guarantee, that PIEteR can be applied in practical situations.

There are four possible applications: 1) decision support at farm and field level; 2) regional and national prediction of root and sugar yields, sugar content and extractability index for industrial campaign planning; 3) yield gap analysis; 4) analysis of regional or national results

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[1] Operating receipts are defined as the gross financial results of sugar beet growing; more information is given in Smit *et al.* (1995b).

[2] PIEteR supports decision making for a limited number of decisions; however, no attention was paid to the quality of the activities at farm or field level that resulted from the decisions taken, nor were decisions on other aspects of sugar beet growing considered.

of the sugar beet processing campaign for development of new information on new cropping techniques, new cultivars, etc. Each of the possible applications is discussed below.

11.3.1 Decision support at farm and field level

Sugar beet growers use advice of extension services to decide on the level (and the method) of N-fertilization and plant density (Smit *et al.*, 1995a,b) and possibly the need to resow (Smit *et al.*, 1996d), but PIEteR could be a help to quantify the effects of optimal or non-optimal levels on N-fertilization and/or plant density on yield, quality, operating returns and impact on environment. Decisions on delivery and/or harvest dates have been discussed in Smit *et al.* (1996c). Given the (simulated) effects of sowing date, soil characteristics, weather conditions, N-availability and plant density, the grower can use PIEteR as a tool to opt for certain delivery periods and harvest dates. Especially the expected date(s) of exceeding the quota level and the risks of an increase in tare content may be helpful to take balanced decisions.

Application of farm or field specific yield and extractability levels instead or besides regional levels may be necessary to improve the accuracy of PIEteR and to account for the (mostly large) variation within a region or even within a farm. These levels can be calculated with PIEteR from historical data on root and sugar yields and extractability index, adapting the theoretical levels to those that were actually established. Corrections for cultivar effects may also be necessary.

The present version of PIEteR can be regarded as a model for potential sugar beet production without irrigation, whereas addition of modules for the effects of irrigation, diseases, nematodes, etc. could specify which results may be expected in alternative situations. More attention to this subject is given in section 11.4. A weak spot in the model concerns the losses of beets and beet tips during harvest; as a rule of thumb, losses of 15% are assumed, but it is difficult to give precise estimations for different conditions and harvesters.

11.3.2 Regional and national harvest predictions

The Dutch Institute for Sugar Beet Research (IRS) and the sugar industry cooperate in national and regional yield and quality predictions as a basis for detailed logistic planning of sugar beet transportation and production, and storage and sale of sugar (Crals and Stinglhamber, 1992). A difference of 1% between predicted and observed total yields equals a difference of about 75000 tonnes of sugar beets, approximately the total daily Dutch processing capacity (T. Schiphouwer, Suiker Unie, pers. comm., 1996); a 'normal' prediction error of 3% can already have great consequences for either the premiums that have to be paid to compensate for losses from early harvesting or the high costs of working hours during Christmas time.

So far, IRS and the sugar industry have used different models for predictions of regional and national yields or quality. IRS aims at predicting root and sugar yields on August 15th with a maximum error of 3%. However, in many years in the period 1981 - 1993, this goal was not reached (D. Hoogerkamp, IRS, pers. comm., 1994). Moreover, the predictions were based on data that were gathered by a labour intensive method in which 250 fields were sampled 10 or 11 times during the growing season, as described in Smit and Struik (1995b). To improve the predictions and to reduce the costs of sampling, IRS and the sugar industry have developed and introduced a model that could be described as a simple, regional version of PIEteR, based on the same initial work (Biemond *et al.*, 1989; T. Schiphouwer, Suiker Unie, pers. comm., 1995). Because of the resemblance [3] between the regional model of Schiphouwer and PIEteR, (parts of) the latter, in particular the water balance module, can contribute to improve the first one.

11.3.3 Yield gap analysis

When the adaptations in 11.3.1, mainly on field specific yield and quality levels, have been made, differences between observed and simulated results will still occur [4]. On average, simulated root and sugar yields, sugar content, extractability index and operating receipts will probably more often be higher than the observed values than lower, due to stress factors, e.g. diseases. In such cases, the simulation results of PIEteR signal that one or more factors may not be optimal, stimulating the grower to monitor yield determining, limiting or decreasing factors. This may for example lead to a diagnosis of the presence of nematodes. The resulting loss of revenues can be calculated with PIEteR, showing the grower the costs that he can afford to overcome the signalled problem in the current growing season or in a following year. A comparison between observed results from non-irrigated and simulated results of irrigated fields for example gives the grower a tool to analyse whether irrigation is profitable. To reach that goal, the effectiveness of irrigation during a series of several years must be studied and the fixed costs of irrigation equipment must be taken into account (Smit *et al.*, 1996b).

For the goal of decision support (11.3.1), it is sufficient to give relative output values of PIEteR, but for yield gap analysis absolute values of root and sugar yields, sugar content and

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[3] The basic idea of both models was the same, but Schiphouwer's version was developed for regional use, whereas PIEteR was made field specific (Smit *et al.*, 1994).

[4] It is important to realize that all simulations in this thesis have been run after harvest, i.e. with all weather data available. In practice, PIEteR will be run during the growing season and make use of current weather data until the day of prediction and of average weather data over about 30 years afterwards (Smit *et al.*, 1996c). As a consequence, the reliability of the predictions usually increases during the growing season. But even when all weather data are available, PIEteR does not give perfect predictions. In general, the model overestimated low observed values of yield, quality and financial parameters and underestimated high observed values. Therefore, its prediction errors were not simple a matter of general level (Smit *et al.*, 1996a).

extractability index are required; when growth limiting or reducing factors are present, the absolute levels of current and potential results will surely be different, whereas the optimal combination of N-availability, plant density and harvest date (expressed in relative values) may be the same for both situations (Smit *et al.*, 1996a).

11.3.4 Evaluation of cropping techniques

Part of the sugar beet growers takes part in a programme of the sugar industry, in which growers' information on the growing season, cultivars and cropping techniques is gathered and linked to industrial output data on yield and quality. The combined data set is analysed to find relationships between growers' techniques and cultivars on one hand and technical and financial parameters on the other. PIEteR could be used as an 'objective' tool for comparison of the effects on different fields, farms and regions, as described in 11.3.3, contributing to reliable conclusions which are based on proper processing of reliable data. Comparison of observed values for fields on which a new cropping technique has been applied, with predicted values for fields on which 'normal' grower's practices have been applied, helps to analyse the effects of the new method. When output parameters from commercial fields are analysed, control and duplicate fields are often absent. PIEteR can be tool to provide (part of) the solution to this problem.

11.4 Additional research

As mentioned in paragraph 11.3.1, PIEteR can be regarded as a basic model for 'normal' conditions. A lot can be done to improve the current version. Two types of improvement can be distinguished: 1) improvement of existing modules, and 2) development of additional modules for other than standard conditions and decisions.

In the following paragraphs, an inventory of problems is given and possible ways of improvement are listed, including their feasibility and relevance for the accuracy of the predictions. In some cases, prediction errors are expressed in guilders per ha; for the calculations, the following assumptions are made: 1) root yield = 60 tonnes.ha^{-1}, 2) sugar content = 16% and 3) payment regulations as applied in this thesis, according to Menu (1993): 0.115 kfl (1 kfl = 1000 Dutch guilders) per net ton of sugar beets, corrected with 9% per percent sugar content above or under 16% and a penalty of 0.022 kfl.(ton tare)$^{-1}$ with a free amount of 75 kg.(net ton beet)$^{-1}$.

11.4.1 Improvement of existing modules

Some of the modules in PIEteR do not always give satisfactory results. Extension of the respective modules with more or more fundamental parameters, making PIEteR a more mechanistic model, may lead to improvements:

1 Sugar content. In the current version of PIEteR the sugar content is calculated as the ratio between simulated sugar and root yields (as a percentage). Although both are predicted with a certain accuracy (with relative prediction errors of 12% and 13% respectively, and explained variances of 52% and 51% respectively for all commercial and experimental fields in the final test; Smit *et al.*, 1996a), the variance of the sugar content accounted for is still very low (4%; the prediction error is only 5%). Smit *et al.* (1996a) list several possible explanations for this problem, which could be used to improve the sugar content predictions in PIEteR. Improvement of sugar content predictions in order to improve the ability of PIEteR for decision support could be a research topic with high priority, since about 40% of the prediction error of the operating receipts is explained by the error of the sugar content. Assuming that this error can be halved as a result of the suggested improvement, the prediction error of the operating receipts would decrease by 0.22 $kfl.ha^{-1}$.

2 Potential levels of root and sugar yields and (K + Na) and α-amino-N contents [5]. The current version of PIEteR contains regional levels for the parameters listed. However, including relationships between potential levels of root and sugar yields and quality parameters on one hand and soil characteristics, such as potential rooting depth, soil water level and contents of calcium carbonate, on the other would increase the field specificity of the model and decrease the need for corrections at field or farm level. But when the extra soil data required to run such a module are difficult to obtain, our aim to use information that the farmer can collect simply and cheaply, is not met any longer (Smit and Struik, 1995a).

   An alternative and easier method to improve the field specific predictions is deriving potential yield and quality levels from historical data at farm and field level. A good and more extensive record keeping is then required. A problem faced especially for commercial fields is that often not just a field but a part of it or more than one field is harvested and/or delivered at a time, so that exact field specific data are hard to find.

   Assuming that the absolute prediction error of root yield could decrease from 0.83 $kg.m^{-2}$ (Smit *et al.*, 1996a) to 0.4 $kg.m^{-2}$ as a result of one of the improvements listed, the prediction error for operating receipts would decrease from 1.07 $kfl.ha^{-1}$ to 0.46 $kfl.ha^{-1}$.

3 The water balance calculations in the production phase. Sugar beet is a deep-rooting crop; this characteristic has an effect on its potential production. Some of the assumptions in the

[5] The respective levels were calculated as the average values of the 11 IRS-regions over the period 1984 - 1988, gathered by IRS (Smit and Struik, 1995b). Since the effects of diseases and pests were small during this period, the average observed values were assumed to equal more or less the 'potential' ones.

water balance module are not always valid in the production phase and could be improved:

a Maximal rooting depth was set at 1.0 m. However, impenetrable soil layers could limit the actual rooting depth and water transport in some soils, whereas roots in other soils reach a length of 2 m or more.

b The water balance module calculates reduction of emergence, growth and production rates from deviations of the pF value in the upper 25 cm soil layer from the optimal value, 2.35. Water transport to and from this layer (evapotranspiration, rainfall, capillary and gravity driven transport from and to deeper soil layers) is simulated, so that the moisture content of the upper layer gives an indication of the moisture content of deeper layers as well. Nevertheless, deeper rooted soil layers often contain more moisture than the upper layer and contribute relatively more to the water supply of the crop. Taking deeper soil layers into account would probably improve the accuracy of the model. In order to include these effects, the *lutum* and organic matter contents of the different soil layers have to be known as well as the distribution of roots as a function of depth and time. More research on the root distribution and the effects of soil type and weather conditions on the distribution is necessary.

Such extensions would require a large research programme and detailed information on the soil structure over a depth of at least 2.0 m. The same is true for the development of a module for irrigation; this topic is elaborated in the next paragraph. Assuming that the proposed improvements would decrease the average (over different soil types) prediction error for root yield by 2%, then the error for the operating receipts would decrease by 0.14 $kfl.ha^{-1}$.

4 The tare module. Including effects of harvest equipment and fine tuning of harvest equipment could improve this part of PIEteR, but proper data are probably not available. Assuming that the required data can be collected, so that the prediction of the tare content could be improved by 5%, then the error for operating receipts decreases by 0.1 $kfl.ha^{-1}$.

11.4.2 Development of additional modules for other than standard conditions and decisions

The current version of PIEteR deals with decisions that have to be made for every sugar beet field; new modules have to be developed in order to decide on other standard or more specific conditions:

1 A module for organic N-supply. Effects of efficiency of organic N-supply compared to inorganic N-fertilization and of increasing levels of N in the soil that can be mineralised during the growing season, have to be taken into account. So far, the effects of N-availability on yield and quality have been considered constant during the growing season. However, the effects may be different in different phases of the growing season and for different fields. Addition of a soil N module, possibly including N-mineralisation, leaching

and denitrification, would be most successful if in all phases the quantitative effects of N-availability on the different yield, quality and environmental parameters would be known; this is probably not the case, although much effort has been done to model the N-fluxes in soils and crops (Smit *et al.*, 1995b). Assuming that a more advanced knowledge may decrease the amount of N-fertilization required by 30 kg.ha^{-1} without affecting yield or quality, cropping costs decrease by 0.03 kfl.ha^{-1}. Besides, the amount of N lost through denitrification and possibly leaching during the growing season as well as the possible losses of N from post-harvest crop residues could be reduced, which is an increasingly important factor in the face of tightening environmental regulations (Smit *et al.*, 1995b).

2 Modules for weeds, diseases and pests. Lately, researchers have given attention to the quantitative effects of weeds (Kropff *et al.*, 1993) and diseases such as Rhizomania disease (Tuitert, 1994), Cercospora leaf spot, Rhizoctonia root rot, Yellowing disease (De Koeijer and Van der Werf, 1995) and nematodes on sugar beet yield and quality. When data on weed or disease infestation are available and the relationships with yield and quality reductions are included in PIEteR, yield and quality predictions may be improved. Such modules also produce estimates of the profitability of crop protection measures. The losses involved strongly depend on the degree of infestation and the resistance of the cultivar grown. A decrease of root yield by 5% results in a decrease of operating receipts by 0.35 kfl.ha^{-1}.

Decisions on weed control have to be taken regularly during spring and early summer. The expert system BETAKWIK, which replaced the more complicated system BETA (Smit *et al.*, 1994), contains information on herbicides, their characteristics, application possibilities, prices and effectiveness towards different weed species in different growth stages of the beets as well as the weeds. Such an expert system can be a useful tool to select the best herbicide for given conditions. However, choices have also to be made between different types of herbicide application, for example a combination of row application of herbicides and mechanical hoeing between rows. Since different systems of weed control require different amounts of time, the grower must take the other crops on the farm into account as well. A project by De Buck *et al.* (1996) pays attention to the problems raised and gives promising preliminary results.

3 An irrigation module. In The Netherlands, an estimated 30000 ha out of 115000 ha of sugar beets are grown on soils with frequent drought stress. Once in about ten years, drought stress also occurs on other soils.

A first impression of the possible effects of irrigation is given when a soil moisture reduction factor equal to 1 is assumed for every day during the growing season, or, in other words, irrigated test fields are considered as fields without water stress. However, this is only true when a number of conditions is met:

* The irrigation is perfectly timed, so that drought stress does not occur during the days before irrigation.
* The amount of water supplied is enough to avoid drought stress but not enough to induce oxygen shortage.
* The soil structure and the crop composition are not affected by the irrigation activities.

A module to include the factors listed would be a useful addition to the model and could also make cost-profit calculations possible. The costs and returns involved could be more than 1 $kfl.ha^{-1}$ on drought stress susceptible soils in dry summers, since not only operational and tactical but also strategic decisions may be supported, especially on the purchase of irrigation equipment with a calculated minimum capacity. For example, an irrigation equipment with a capacity of 60 $m^3.hour^{-1}$, a replacement value of 42.3 kfl and annual costs of 18.2% (Roeterdink and Haaksma, 1993) costs 7.7 $kfl.year^{-1}$, not including extra tractor and fuel costs. Assuming that the quality of the prediction is improved by 2% over a series of years, the prediction error of the operating receipts would decrease by 0.14 $kfl.ha^{-1}$.

4 A module for storage losses. A preliminary module has been developed during the project, but more research is necessary for a good scientific basis. With good storage conditions, losses will be about 150 $g.ton^{-1}.day^{-1}$ (Houtman, 1988), equalling an amount of 0.1 $kfl.ha^{-1}$ for a two-week storage period. With non-optimal storage conditions, caused by high temperatures or high tare contents, for example, losses can be much higher. However, correct simulation of the processes involved is difficult. Part of the prediction error of the operating receipts caused by neglecting storage losses is overruled by the error of the predictions until harvest date.

5 A module for cultivar differences. So far, general patterns have been included into PIEteR, not taking cultivar differences into account. In recent years, differences in production patterns between newly developed cultivars have increased, for example leading to different relationships of the extractability index with N-availabilities and of the dirt tare content with high *lutum* contents. The ability to suppress weed development also varies among cultivars. According to the 70th list of cultivars of field crops in The Netherlands (CPRO-DLO, 1994), the difference in operating receipts between cultivars grown with average or favourable conditions can be 4% at maximum, equalling 0.28 $kfl.ha^{-1}$. On average, this will be less, for example 0.14 $kfl.ha^{-1}$.

6 So far, no attention has been paid to the effects of the preceding crop on root yield, but it is said that the effect can be 5% at maximum (D. Zoeteman, pers. comm., 1995), equalling an amount of 0.35 $kfl.ha^{-1}$. On average, this could be 2% or 0.14 $kfl.ha^{-1}$.

7 Smit *et al.* (1996b) described the integration of decisions in sugar beet growing with factors in the crop rotation and farm organisation, both on a short and a long term. Modules to include real data on crop yields, equipment and labour availability instead of normative

ones would be helpful to generate more realistic predictions of returns above allocated variable costs and/or above allocated fixed costs.

In decision making during the growing season ('(semi-)operationally') as well as on longer term ('tactically' and 'strategically'), one would wish to combine PIEteR with similar models for the other crops in the rotation, combined with an optimization procedure for labour input, application of different methods of crop protection, investments, etc. The added value of such an approach in comparison with linear programming models is that the effects of current and expected weather conditions can be considered, including for example risks of harvest problems and frost damage in sugar beets (Smit *et al.*, 1996c). The more static approach of linear programming techniques could then be modified by the results of the combined simulation models. A stochastic approach might be an alternative, but fails because of the infinite number of possible states of the crop. This is in contrast with animal husbandry problems, in which a number of clear, irreversible transition processes occurs. Another difference is the number of quantified observations in animal husbandry, especially in the dairy sector, where daily registration of body temperature, milk yield and quality can supply the farmer with many data. Indications for abnormal conditions are easier recognized and there are more opportunities to take action.

8 For practical use, the current version of PIEteR has to be made user-friendly. It must be easy and clear for the grower to insert the data required for model runs, for example sowing date and planned levels of N-fertilization, plant density and harvest date. The output data must be presented in tables and/or figures, that are easy to understand and analyse, both on screen and on paper. The database of the decision support system must contain all relevant weather data for all weather stations required over a period of 30 years, so that realistic analyses can be made on the average expected weather conditions during the (remaining part of the) growing season and the risks that go with certain choices. Finally, it must be easy to calculate the effects of decisions and to make cost-benefit calculations in considering alternative solutions to a decision problem.

11.5 Conclusion

PIEteR can be used as a basis for a decision support system for sugar beet growers and sugar industry. It gives quantitative insight into the effects of decisions on N-fertilization, plant density and harvest date on the yield, quality, returns and impact on environment.

In some of our test cases, the predicted output of PIEteR differed greatly from the output observed. A better recording of growth limiting and growth reducing factors at field level would make the differences smaller. However, PIEteR itself is not a perfect model of reality, especially not with 'extreme' conditions; PIEteR tends to overestimate yield, quality and financial parameters with very unfavourable conditions and to underestimate them with very favourable conditions. Not all growth limiting and reducing factors have yet been included in the model.

Since the simulations of PIEteR have certain prediction errors, decision support on N-fertilization, plant density and harvest date at farm and field level could better be attained with relative than absolute output values. It is assumed that the optimal levels of the three factors in real life are not (greatly) affected by factors which have not (yet) been included in the model. Large differences between predicted and observed output parameters would make the model unreliable in the growers' eyes beforehand, even when the optimization of decisions would be correct and successful.

Nevertheless, on a longer term, the ability of PIEteR to produce reliable absolute output values should be improved as well. Different improvements and additions have been listed in Paragraphs 11.4.1 and 11.4.2, respectively. From the view point of a decision support system and its requirements for accurate predictions, the most important improvements proposed are those on sugar content, field specific yield and quality levels, and water balance calculations. Additional modules on the effects of weeds and diseases, irrigation, cultivar, preceding crop and on organic nitrogen fertilization and the N-balance would be helpful, the latter mainly as a help to decrease N-losses. However, the proposed improvements will require a large additional research input. Basic ideas and part of the information required are available. The challenge of improving our physiological knowledge about a 'common' crop and its practical applicability in decision support is worth funding.

The improvements proposed have different effects on the quality of the decision support model. On the other hand, some improvements are easier to carry out than others. Some of the improvements with relatively little effect on the quality of the model may be applied earlier than some of those with relatively much effect, so that some of the improvements with relatively little complexity may be more advisable than some of the more complex ones. Table 1 gives an overview of the improvements proposed and the two characteristics mentioned for each of them, as well as the summarizing characteristic 'efficiency'. Improvements on the potential levels of parameters seems to be the most important option, followed by addition of modules for weeds, diseases and pests, cultivar differences and preceding crops.

Fields were a central level of aggregation in this study. With the development of precision agriculture, the opportunity increases to support decisions on especially nitrogen fertilization on a lower level, i.e. on parts of fields which have a certain homogeneity for soil type and nitrogen stock.

For practical use by sugar beet growers, the current version of PIEteR must be made user-friendly, so that more potential users can apply the model without assistance of computer-experts. Considering the fast increase of number and distribution of personal computer

Table 1 Improvements of PIEteR, proposed in this chapter, with their respective effects on the quality of the decision support model, their relative degrees of 'easiness' to be carried out and the summarizing characteristic 'efficiency' of the development of the improvement proposed.

Number [1]	Improvement proposed	Quality of prediction [2]	'Easiness' [3]	Efficiency [4]
11.4.1.1	Sugar content module	+++	+	++
11.4.1.2	Potential levels of parameters	+++++	++	++++
11.4.1.3	Water balance module	++	+	++
11.4.1.4	Tare module	+	+	+
11.4.2.1	Organic N-supply module	+	++	++
11.4.2.2	Modules for weeds, diseases and pests	++++	+	+++
11.4.2.3	Irrigation module	++	++	++
11.4.2.4	Module for storage losses	+	++	++
11.4.2.5	Module for cultivar differences	++	++++	+++
11.4.2.6	Module for effect of preceding crops	++	+++	+++
11.4.2.7	Integration module	0	++	+
11.4.2.8	User-friendliness	0	++	+

[1] The numbers of the improvements refer to the section (11.4.1 or 11.4.2) and their numbers within the respective sections.

[2] The estimated effect of the improvement on the quality of the decision support system, expressed in a decrease of the prediction error of the operating receipts. Meaning of symbols:

0 = no effect
\+ = effect in the range [0, 0.1] $kfl.ha^{-1}$
++ = effect in the range [0.1, 0.2] $kfl.ha^{-1}$
+++ = effect in the range [0.2, 0.3] $kfl.ha^{-1}$
++++ = effect in the range [0.3, 0.4] $kfl.ha^{-1}$
+++++ = effect in the range [0.4, ∞] $kfl.ha^{-1}$

[3] How easier it is to obtain the information required and to develop a method for carrying out the improvement, how greater the 'easiness'. Meaning of symbols:

\+ = extremely difficult
++ = difficult
+++ = moderately difficult
++++ = easy
+++++ = very easy

[4] This column gives the combined efficiency to work on the improvements proposed; the code is more or less the average of the two preceding columns.

facilities and skills, and of helpful expert systems such as BETAKWIK in arable farmers' offices, such a decision support system surely has a promising future.

References

Biemond, T., H.J. Greve, T. Schiphouwer & A.J. Verhage, 1989. PIEteR, semi green-box produktiemodel suikerbieten. Wageningen, WAU, Department of Farm Economics, 31 pp.

Buck, de, A.J., S.R.M. Janssens, A.T. Krikke, H.B. Schoorlemmer & G.A.A. Wossink, 1996. Risico's en risicoperceptie bij duurzame produktiemethoden op het akkerbouwbedrijf. Verslag fasen 1 en 2. Lelystad, PAGV, Interne mededeling, 93 pp.

CPRO-DLO, Wageningen, 1994. 70e Rassenlijst landbouwgewassen 1995. Wageningen, CPRO-DLO, 326 pp.

Crals, M.L. & E. Stinglhamber, 1992. Importance des previsions de production dans la gestion d'une sucrerie. In: Proceedings of the I.I.R.B.-Conference, Brussels, 12-13 February 1992. Brussels, IIRB: 157-168.

Houtman, H.J., 1988. Inventarisatie van onderzoeksresultaten over de bewaring van suikerbieten. Bergen op Zoom, IRS, 21 pp.

Koeijer, de, K.J. & W. van der Werf, 1995. Effect of beet yellowing viruses on light interception and light use efficiency of the sugar crop. *Crop Protection* **14**, 4, 291-297.

Kropff, M.J., S.E. Weaver, L.A.P. Lotz, J.L. Lindquist, W. Joenje, B.J. Schnieders, N.C. van Keulen, T.R. Migo & F.F. Fajardo, 1993. Understanding crop-weed interactions in field situations. In: Kropff, M.J. & H.H. van Laar. Modelling crop-weed interactions. Wallingford, CAB International: 113-245.

Menu, W.J.L., 1993. Wijziging kwaliteitsbetaling suikerbieten. *Maandblad Suiker Unie* **27**, 6-7.

Roeterdink, H.W. & J.J. Haaksma, 1993. Kwantitatieve informatie voor de akkerbouw en de groenteteelt in de vollegrond. Bedrijfssythese 1993-1994. Lelystad, IKC-AGV & PAGV, Publikatie nr. 69, 204 pp.

Smit, A.B., J.H. van Niejenhuis & P.C. Struik, 1994: Introduction to a bio-economic production model for sugar beet growing. In: Struik, P.C., W.J. Vredenberg, J.A. Renkema and J.E. Parlevliet (eds.). Plant production on the threshold of a new century. Proceedings of the International Conference at the occasion of the 75th Anniversary of the Wageningen Agricultural University, Wageningen, The Netherlands, held June 28 - July 1, 1993. Developments in plant and soil sciences, 61. Dordrecht/Boston/London, Kluwer Academic Publishers: 115-122.

Smit, A.B. & P.C. Struik, 1995a: The first step towards a decision support system for sugar beet growing: selection of a basic model. *Journal of Agronomy and Crop Science* **175**, 213-220.

Smit, A.B. & P.C. Struik, 1995b. PIEteR: a field-specific production model for sugar beet growing. *Journal of Agronomy and Crop Science* **175**, 335-348.

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1995a. Modelling the influence of plant density on yield, sugar content and extractability of sugar beet. In: Proceedings of the 58th IIRB-congress, 19-22 June 1995, France. Brussels, IIRB: 413-424.

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1995b. Nitrogen effects in sugar beet growing. A module for decision support. *Netherlands Journal of Agricultural Science* **43**, 4, 391-408.

Smit, A.B., G.J.W. Muijs, P.C. Struik & J.H. van Niejenhuis, 1996a. Evaluation of a model for sugar beet production by comparing field measurements with computer predictions. *Computers and Electronics in Agriculture* (accepted).

Smit, A.B., J.H. van Niejenhuis & J.A. Renkema, 1996b. A farm economic module for tactical decisions on sugar beet area. *Netherlands Journal of Agricultural Science* (submitted).

Smit, A.B., P.C. Struik & J.H. van Niejenhuis, 1996c. Prediction of various effects of harvest date in sugar beet growing. *Journal of Agricultural Engineering Research* (submitted).

Smit, A.B., P.C. Struik, J.H. van Niejenhuis & J.A. Renkema, 1996d. Critical plant densities for resowing. *Journal of Agronomy and Crop Science* (in press).

Tuitert, G., 1994. Epidemiology of rhizomania disease of sugar beet. Wageningen, WAU/Bergen op Zoom, IRS. PhD-thesis, 168 pp.

Summary

PIEteR: a field specific bio-economic production model for decision support in sugar beet growing

This study deals with a field specific crop production model for sugar beet growing, developed as a basis for decision support in sugar beet growing in The Netherlands. Connected with an economic module, a crop model can serve as a basis for decision support at farm and field level.

The main goals of the project were:

1 to develop a growth model for sugar beet as required for decision support;

2 to analyse and quantify the effects of different levels of nitrogen availability, plant density and harvest date on yield, quality, financial returns and environmental aspects;

3 to develop ideas how the relationships derived could be integrated into a decision support system for sugar beet growing in general and specifically at field level.

The main component of the bio-economic model developed is a crop growth model, that simulates crop responses to weather conditions, soil factors and cultural practices, the latter resulting from growers' decisions. The analysis of decisions in sugar beet growing led to the selection of three (semi-)operational decisions that were studied in detail: N-fertilization level, plant density and harvest date. Moreover, the tactical decision on sugar beet area was studied.

From literature, different models were available for use as a basic model. The selected model had to be able to predict root and sugar yields accurately. It had to be possible to include location specific data and new modules, e.g. for nitrogen fertilization, plant density or soil water contents. Finally, the farmer should be able to collect the required input data easily and cheaply.

The basic growth model for the development of a decision support system for sugar beet growing was selected on the basis of an analysis of performance. The selection was made from four dynamic models: (different versions of) SUCROS and SUBEMO, which are complex, mechanistic models, and LINTUL and PIEteR, which are relatively simple regression models including causal relationships at a higher level of integration. In the test, (the prototype version of) PIEteR appeared to be the most accurate model and the other requirements were met as well.

The prototype version of PIEteR was further described, and adapted and extended, considering the goals set. In PIEteR, four phases of growth and production are

distinguished. The first phase or 'emergence phase' starts at sowing date and ends at the day of 50% emergence; its length is mainly determined by temperature, corrected for sub-optimal soil moisture contents. The second phase or 'growth phase' starts at emergence date and ends at the so-called 'growth point date' (GPD), when the beets contain on average 4 g sugar. GPD is the only well-defined developmental stage in the vegetative sugar beet crop. GPD coincides more or less with canopy closure. The length of the growth phase is mainly determined by temperature, corrected for sub-optimal moisture contents. The required temperature sums are different for different regions. Besides GPD, leaf stages (expressed in number of leaves) up to the 10-leaf stage were modelled in PIEteR. The third phase or 'production phase' starts at GPD or, in fact, some days earlier, and ends at harvest. The production of beet and sugar during this phase is mainly determined by radiation intensity, corrected for sub-optimal soil moisture contents and regional effects. Time dependent efficiency functions translate global radiation levels directly into daily root and sugar production. The fourth phase or 'storage phase' starts at harvest date and ends at the day that the beets are delivered to the sugar industry. The losses of sugar during this phase are mainly determined by temperature. Modelling of the processes during the storage phase has not been included in this thesis, because the underlying processes of losses during storage could not be described adequately. A 'ripening' phase is not distinguished from the production phase in the current version of PIEteR.

Tests gave reasonable predictions of emergence date, leaf stages, GPD and root and sugar yields (simulated for every day of the production phase) for fields with 'normal' nitrogen levels in The Netherlands. Besides root and sugar yields and their ratio, the sugar content, the contents of (K + Na) and α-amino-N, and the calculated extractability index as well as the returns were included in the model. (K + Na) and α-amino-N contents were modelled as functions of time after canopy closure. In the calculation of the returns, the payment regulations of one of the Dutch sugar industries in 1993 were applied.

The effects of plant density on all parameters listed were derived from experimental data and included in PIEteR. A test showed that this improved the quality of the model predictions of root and sugar yields, (K + Na) and α-amino-N contents, extractability index and returns.

The equations of plant density effects derived were applied to the decision whether or not to resow the crop in case of poor crop establishment. The maximum plant density, for which resowing is profitable, decreases with time after 1 March. For a heavy clay soil in Wageningen, this number varies between 3.7 plants.m^{-2} with sowing date 28 April and resowing date 26 May to 6.6 plants.m^{-2} with dates 12 April and 20 April, respectively, assuming that resowing leads to a normal crop stand of 8 plants.m^{-2}.

N-availability affects yields and quality of the beets and the amount of leaves and of residual nitrogen in crop residues after harvest. N-availability is defined as the sum of the amount of mineral N in the soil layer 0 - 60 cm in February and the N-fertilizer rate in spring. Both root and sugar yields increase with N-availability to an optimum and decrease beyond. Sugar content and extractability index generally decrease with increasing N-level. The returns are optimal when the N-availability is 180 $kg.ha^{-1}$ or the N-fertilizer rate 130 $kg.ha^{-1}$, assuming that $N_{min,\ 0\text{-}60\ cm,\ February}$ is 50 $kg.ha^{-1}$. Taking the costs of N-fertilizer into account, the optimum N-rate decreases by 20 $kg.ha^{-1}$ when a price ratio between sugar beet and fertilizer of about 1:10 is assumed. The amounts of leaves and N in crop residues increase with increasing N.

The effects listed were derived from experimental data and included in PIEteR. Tests showed that this improved the accuracy of PIEteR for fields with non-optimal N-levels. The improvement was even stronger than through including the plant density module. Moreover, a first indication of expected environmental effects of sugar beet growing was given. For more exact predictions of N-effects on yield, quality and environmental aspects, modules on mineralization, leaching and denitrification have to be included in PIEteR.

Crown and dirt tare contents of sugar beet were modelled as functions of mainly *lutum* and soil moisture contents. The fine tuning of harvest machinery has an overriding effect, so including this factor is necessary to improve the quality of the tare module.

When deciding on harvest dates given fixed delivery dates, the grower has to take risks of severe frost or heavy rainfall in autumn into account. Severe frost can result in damage to unharvested beets; heavy rainfall can cause soil structure damage and high dirt tare rates. The risk of frost damage in unharvested beets proved to be negligible when the crop was harvested before November 10th, as advised by the sugar industry. In general, the risk of rainfall of at least 10 mm per week does not increase during the season.

The question whether the sugar quota may be exceeded or not, plays an important role in balanced decision making on harvest date. Beyond the quota, the ratio between marginal revenues and marginal costs decreases. The marginal revenues decrease since the price of C-beets is significantly lower than the price of quota-beets and the marginal costs increase as a result of increasing tare contents, increasing beet losses and increasing yield depressions in a following winter wheat crop. Therefore, a harvest delay becomes less profitable.

The model was validated on a series of commercial and experimental fields in The Netherlands. Average prediction errors for root and sugar yields and financial returns per ha were 12%, 13% and 13%, respectively, and the variances accounted for were 52%, 51% and 50%, respectively. When for each year, the total predicted root and sugar yields and financial returns over the different commercial fields per farm were compared with the reported ones, the respective prediction errors were 12%, 13% and 14%, and the variances accounted for 90%, 94% and 94%.

In a sensitivity analysis, the effects of integrated decisions on plant density, N fertilization and harvest date on different parameters were studied separately. Changes in harvest date had larger effects on the results than changes in N-fertilization and plant density levels for the field studied.

A number of improvements are necessary: 1) PIEteR needs to be improved for simulation of sugar content; 40% of the prediction error of the returns is explained by the error of the sugar content; 2) variation in local yield and quality levels within a region is an important source of errors. A detailed recording of local growing conditions is one of the possible ways to improve the performance of the model; 3) for application in a decision support system at farm and field levels, relative rather than absolute results may be presented.

For decisions at operational level in sugar beet growing (for example on plant density, nitrogen fertilizer rate and harvest date), returns above allocated variable costs can be used as a criterion for comparing the economics of different options. For (tactical) decisions on sugar beet area, the sugar beet grower has to take into account the opportunity costs of labour and equipment. Two possibilities are considered: 1) the opportunity costs equal nil; equipment and labour are not limiting and cannot be used differently. When the opportunity costs equal nil, then we take the returns above allocated variable costs as a measure for planning; 2) the opportunity costs are positive; labour and equipment are limiting and there are different ways to use them. The opportunity costs can be so high that an increase of the capacity, purchase of land (with quota) and equipment, and an increase of the fixed labour force, are profitable. This level of opportunity costs is more or less the upper level. When an increase of capacity and labour is profitable, then the opportunity costs can be reflected by the allocated fixed costs of labour and equipment. Most farms will have opportunity costs in between nil and the upper level mentioned. In our calculations, both upper and lower limits are taken into account. Different options of land use with given total farm area, equipment and (fixed) labour are compared on the basis of returns above allocated variable and/or fixed costs.

A method of allocating fixed costs to crops in the cropping plan is described and included in PIEteR. Returns above allocated variable and fixed costs were calculated for the most current arable crops in a test set of arable farms in different regions in The Netherlands during 1991 - 1993. Seed and ware potato and sugar beet had the highest returns above allocated variable costs, but when allocated fixed costs were also taken into account, sugar beet appeared to be more profitable than seed potato.

Growing C-sugar beet is not attractive, since prices of C-beets are considerably lower than those of quota-beets; wheat growing is more profitable. However, the estimated area required to grow the exact amount of quota-sugar was uncertain with a standard deviation of ± 10%.

The final discussion concluded that the aim of the project was met; decisions on N-availability, plant density and harvest date can be taken simultaneously (for example as a sensitivity analysis in the preceding winter) but also independently, given fixed levels of the other parameters. Simulations that need to be improved, are: 1) sugar content; 2) the field specific potential yield and quality levels, which have so far been based on regional averages; 3) the number of decisions that are supported. The effects of cultivars, management skills and other factors have not been taken into account. No attention was paid to the quality of the activities at farm or field level that resulted from the decisions taken, nor were other decisions in sugar beet growing considered.

PIEteR can be applied in decision support at farm and field level, regional and national harvest predictions (for planning of the processing campaign of the sugar industry), in analysis of differences between current and potential yields (to signal growth limiting or decreasing factors) and in evaluating cropping techniques. PIEteR can be regarded as a basic model for 'normal' conditions. Additional research is necessary to improve existing modules and to develop additional modules for other than standard conditions and decisions. Research on sugar content, potential levels of root and sugar yields and (K + Na) and α-amino-N contents, and the water balance and tare modules may improve the current version of the model. Additional modules on the effects of weeds, diseases and pests, irrigation, cultivar, preceding crop and on organic nitrogen fertilization and the N-balance (mainly as a help to decrease N-losses) may be helpful to extend the applicability of the model. When the expected effects of the proposed improvements on the quality of the decision support system and the 'easiness' to carry them out are considered simultaneously, improvements of the potential field specific levels of yield and quality parameters seem to be the most important option, followed by addition of modules for weeds, diseases and pests, cultivar differences and preceding crops.

For practical use, the current version of PIEteR must be made user-friendly, so that more potential users can apply the model without assistance of computer-experts. The development of an expert system such as BETAKWIK, which is currently applied by growers, shows that a decision support system such as PIEteR has a promising future.

Samenvatting

PIEteR: een perceelsspecifiek bio-economisch produktiemodel voor beslissingsondersteuning in de suikerbietenteelt

In dit proefschrift is een perceelsspecifiek model beschreven, dat ontworpen is als basis voor een beslissingsondersteunend systeem voor de suikerbietenteelt in Nederland. Gekoppeld aan een economische module kan het dienen als basis voor beslissingsondersteuning op bedrijfs- en perceelsniveau.

De belangrijkste doelen van het project waren:

1 de ontwikkeling van een groeimodel dat geschikt zou zijn voor beslissingsondersteuning;

2 het analyseren en kwantificeren van de invloeden van N-beschikbaarheid, plantaantal en oogstdatum op opbrengst, kwaliteit, financiële resultaten en milieu-aspecten;

3 de ontwikkeling van ideeën over hoe de afgeleide relaties geïntegreerd kunnen worden in een beslissingsondersteunend model voor suikerbieten in het algemeen en specifiek op perceelsniveau.

Het hoofdbestanddeel van het ontwikkelde bio-economische model is een gewasgroeimodel, dat de reactie van het gewas op weersomstandigheden, bodemfactoren en teeltmaatregelen simuleert, waarbij de laatste voortkomen uit beslissingen van telers. De analyse van beslissingen die in de suikerbietenteelt genomen worden, leidde tot de keuze van drie (semi-)operationele beslissingen die in detail bestudeerd werden: N-gift, plantaantal en oogstdatum. Daarnaast werd de tactische beslissing ten aanzien van het areaal suikerbieten onderzocht.

In de literatuur werden verschillende modellen gevonden die als basismodel konden dienen. Het te kiezen model moest in staat zijn om wortel- en suikeropbrengst nauwkeurig te voorspellen. Locatiespecifieke gegevens en nieuwe modules moesten opgenomen kunnen worden, bijvoorbeeld voor stikstofbemesting, plantaantal of bodemvochtgehalte. Tenslotte moest het voor de boer mogelijk zijn om de benodigde invoergegevens gemakkelijk en goedkoop bijeen te brengen.

De volgende vier dynamische modellen werden getest: twee complexe, mechanistische modellen, (verschillende versies van) SUCROS en SUBEMO, en twee relatief eenvoudige, causale regressiemodellen op een hoger integratieniveau, LINTUL en PIEteR. Uit de test kwam (de prototype-versie van) PIEteR als het meest nauwkeurige model naar voren. Bovendien voldeed dit model ook aan de overige gestelde eisen.

De prototype-versie van PIEteR is vervolgens nauwkeuriger beschreven, en aangepast en uitgebreid overeenkomstig de gestelde doelen. In PIEteR worden vier groei- en produktiefasen onderscheiden. De eerste fase of 'opkomstfase' begint op de zaaidatum en eindigt op de dag dat 50% van de planten opgekomen is; de duur van deze fase wordt voornamelijk bepaald door de temperatuur, waarbij gecorrigeerd wordt voor niet-optimale bodemvochtgehaltes. De tweede fase of 'groeifase' begint op de opkomstdatum en eindigt op de zogenaamde 'groeipuntsdatum' (GPD), de dag waarop de bieten gemiddeld 4 g suiker bevatten. GPD is daarmee het enige goed gedefinieerde ontwikkelingsstadium voor het vegetatieve gewas suikerbieten. GPD valt min of meer samen met het moment van sluiting van het gewas. De duur van de groeifase wordt voornamelijk bepaald door de temperatuur, met correcties voor niet-optimale bodemvochtgehaltes. De benodigde temperatuursom verschilt echter per regio. Naast GPD zijn de bladstadia (uitgedrukt in aantallen bladeren) tot en met het 10-bladstadium gemodelleerd en in PIEteR opgenomen. De derde fase of 'produktiefase' begint enkele dagen vóór GPD en eindigt op de oogstdatum. De produktie van wortel en suiker tijdens deze fase wordt voornamelijk bepaald door de stralingsintensiteit, waarbij gecorrigeerd wordt voor niet-optimale bodemvochtgehaltes en regionale invloeden. Efficiëntieparameters vertalen globale stralingsniveaus rechtstreeks naar dagelijkse wortel- en suikerproduktie. Deze parameters zijn afhankelijk van het tijdstip na GPD. De vierde fase of 'bewaarfase' begint op de oogstdatum en eindigt op de dag dat de bieten afgeleverd worden aan de suikerindustrie. De suikerverliezen in deze fase worden voornamelijk bepaald door de temperatuur. Het modelleren van de processen tijdens de bewaarfase is niet in dit proefschrift opgenomen, omdat deze processen, die tot verliezen in de bewaarfase leiden, nog onvoldoende duidelijk beschreven kunnen worden. In de produktiefase van de huidige versie van PIEteR is geen aparte 'rijpingsfase' onderscheiden.

Tests gaven aanvaardbare voorspellingen van opkomstdatum, bladstadia, GPD en wortel- en suikeropbrengsten (gesimuleerd op iedere dag van de produktiefase) voor percelen met 'normale' stikstofniveaus in Nederland. In het model werden opgenomen: wortel- en suikeropbrengsten, hun verhouding, het suikergehalte, de (K + Na)- en α-amino-N-gehaltes, de berekende winbaarheidsindex en de financiële opbrengst. De (K + Na)- en α-amino-N-gehaltes zijn gemodelleerd als functies van de tijd na het sluiten van het gewas. In de berekening van de financiële opbrengst zijn de uitbetalingsregels van 1993 van één van de Nederlandse suikerindustrieën toegepast.

Uit experimentele gegevens werden de invloeden van plantaantal op alle genoemde parameters afgeleid en vervolgens in PIEteR ingebouwd. Hierdoor bleken de voorspellingen door het model van de wortel- en suikeropbrengst, de (K + Na)- en α-amino-N-gehaltes, de winbaarheidsindex en de financiële opbrengst verbeterd te worden.

De formules voor de invloeden van het plantaantal zijn toegepast op de beslissing om al dan niet over te zaaien bij een slechte stand van het gewas. Het maximale plantaantal waarbij overzaai aantrekkelijk is, daalt naarmate de tijd verstrijkt (na 1 maart). Voor een perceel zware klei in Wageningen varieert dit aantal tussen 3.7 planten.m^{-2} als gezaaid wordt op 28 april en overgezaaid wordt op 26 mei, en 6.6 planten.m^{-2} bij zaai op 12 april en overzaai op 20 april. Hierbij is er van uitgegaan dat na overzaai een normaal gewas met 8 planten.m^{-2} tot stand komt.

De beschikbaarheid van stikstof beïnvloedt de opbrengst en kwaliteit van bieten en daarnaast de hoeveelheden loof en reststikstof in gewasresten die na de oogst op het land achterblijven. De beschikbaarheid van stikstof is hier gedefinieerd als de som van de minerale N-voorraad in de bodemlaag 0 - 60 cm in februari en de N-kunstmestgift in het voorjaar. De wortel- en suikeropbrengst nemen beide met toenemende N-beschikbaarheid toe tot een zeker optimum en dalen daarboven weer. Het suikergehalte en de winbaarheidsindex dalen in het algemeen met toenemend N-niveau. De uitbetaling is optimaal bij een N-beschikbaarheid van 180 kg.ha^{-1} ofwel een N-gift van 130 kg.ha^{-1} bij een bodemvoorraad van 50 kg.ha^{-1} in februari. Als de kosten van N-kunstmest in de berekening worden meegenomen daalt de optimale N-gift met 20 kg.ha^{-1}. Deze berekening geldt voor een prijsverhouding van suikerbiet ten opzichte van meststof van 1:10. De hoeveelheden loof en N in gewasresten nemen toe met toenemende N-beschikbaarheid.

De genoemde relaties zijn afgeleid uit experimentele gegevens en in PIEteR ingebouwd. Uit tests bleek dat hierdoor de nauwkeurigheid van de voorspellingen van PIEteR op percelen met niet-optimale N-niveaus toenam. De verbetering was zelfs sterker dan bij het inbouwen van de plantaantalmodule. Bovendien werd een eerste indicatie van verwachte milieu-effecten in de suikerbietenteelt verkregen. Als meer nauwkeurige voorspellingen van de stikstofinvloeden op opbrengst, kwaliteit en milieu-aspecten gewenst zijn, moeten ook modules voor mineralisatie, uitspoeling en denitrificatie in PIEteR worden opgenomen.

Kop- en grondtarra bij suikerbieten werden gemodelleerd als functies van met name *lutum-* en bodemvochtgehaltes. De afstelling van oogstmachines heeft echter een zodanig dominerende invloed dat verbetering van de tarramodule alleen maar tot stand kan komen als deze factor in het model wordt opgenomen.

Als er bij gegeven afleverdata beslissingen over oogstdata genomen moeten worden, moet de teler de risico's van zware vorst of hevige regenval in de herfst in zijn beschouwingen meenemen. Door vorst kan schade aan ongeoogste suikerbieten ontstaan; hevige regenval kan schade aan de bodemstructuur en hoge tarragehaltes veroorzaken. Het risico op vorstschade aan ongeoogste bieten bleek verwaarloosbaar bij oogst vóór 10 november, de dag die door de suikerindustrie als laatste oogstdatum geadviseerd wordt. In het algemeen neemt het risico op minstens 10 mm neerslag per week gedurende het oogstseizoen niet toe.

De vraag of het suikerquotum overschreden zal worden of niet, speelt een belangrijke rol bij evenwichtige besluitvorming over de oogstdatum. Bij overschrijding van het quotum daalt de verhouding tussen marginale opbrengsten en marginale kosten. De marginale opbrengsten dalen doordat de prijs van C-bieten duidelijk lager is dan voor quotumbieten en de marginale kosten stijgen door toenemende tarragehaltes, bietverliezen en hogere opbrengstreducties van het volggewas wintertarwe. Uitstel van de oogst wordt hierdoor minder aantrekkelijk.

Het model werd gevalideerd op een serie Nederlandse praktijk- en proefpercelen. De gemiddelde voorspellingsfouten voor wortel-, suiker- en financiële hectare-opbrengsten bedroegen respectievelijk 12%, 13% en 13%, terwijl de verklaarde varianties 52%, 51% en 50% bedroegen. Wanneer voor elk jaar de voorspelde wortel-, suiker- en financiële opbrengsten van de verschillende praktijkpercelen gesommeerd werden per bedrijf en vergeleken werden met de gerapporteerde, waren de voorspellingsfouten respectievelijk 12%, 13% en 14% en de verklaarde varianties 90%, 94% en 94%.

Er werd apart aandacht besteed aan de invloeden van geïntegreerde beslissingen, bijvoorbeeld bij analyses in de winter voorafgaande aan de teelt, ten aanzien van plantaantal, N-bemesting en oogstdatum, op de verschillende parameters. Op het bestudeerde perceel hadden veranderingen in oogstdatum meer invloed op de resultaten dan veranderingen in N-bemesting en plantaantal.

Een aantal verbeteringen is nodig: 1) de simulatie van het suikergehalte door PIEteR moet verbeterd worden; 40% van de voorspellingsfout van de uitbetaling wordt verklaard door de fout in het suikergehalte; 2) de variatie in plaatselijke opbrengst- en kwaliteitsniveaus binnen een regio is een belangrijke bron van fouten. Een nauwkeurige registratie van de lokale groei-omstandigheden is één van de mogelijke bijdragen tot betere resultaten van het model; 3) bij toepassing in een beslissingsondersteunend systeem op bedrijfs- en perceelsniveau is het beter om relatieve in plaats van absolute resultaten te presenteren.

Bij beslissingen in de suikerbietenteelt op operationeel niveau (bijvoorbeeld over plantaantal, stikstofgift en oogstdatum) kunnen saldi na aftrek van toegerekende variabele kosten gebruikt worden als criterium om verschillende opties ten aanzien van hun economische aantrekkelijkheid te vergelijken. Bij (tactische) beslissingen omtrent het suikerbietenareaal doet de teler er verstandig aan de ontgane opbrengsten (Engels: 'opportunity costs') van arbeid en machines ook in de beschouwing mee te nemen. Twee mogelijkheden worden beschouwd: 1) de ontgane opbrengsten zijn gelijk aan nul; machines en arbeid zijn niet limiterend en kunnen niet alternatief worden aangewend. In dit geval nemen we de saldi na aftrek van toegerekende variabele kosten als planningsmaatstaf; 2) de ontgane opbrengsten zijn groter dan nul; arbeid en machines zijn limiterend en er zijn alternatieve aanwendingsmogelijkheden. De ontgane opbrengsten kunnen zo hoog zijn dat uitbreiding van de capaciteit aantrekkelijk wordt, zoals aankoop van land (met quotum) en machines, en uitbreiding van de vaste arbeid. Dit niveau van ontgane opbrengsten is min of meer het plafond. In het laatste geval kunnen de ontgane opbrengsten benaderd worden door de toegerekende vaste kosten van arbeid en machines. De meeste boeren zullen ontgane opbrengsten hebben die zich bevinden tussen nul en het genoemde plafond. In onze berekeningen zijn zowel het plafond als het nul-niveau meegenomen. Verschillende opties voor landgebruik bij gegeven totale bedrijfsoppervlakte, machines en (vaste) arbeid zijn met elkaar vergeleken op basis van de saldi na aftrek van toegerekende variabele en/of vaste kosten.

Beschreven is een methode om vaste kosten aan gewassen in een bouwplan toe te rekenen; deze methode is in PIEteR toegepast. Voor de meest gangbare akkerbouwgewassen werden saldi na aftrek van toegerekende variabele en vaste kosten berekend voor een testbestand van akkerbouwbedrijven in verschillende regio's in Nederland gedurende de jaren 1991 - 1993. Poot- en consumptie-aardappelen en suikerbiet hadden de hoogste saldi na aftrek van toegerekende variabele kosten, maar als de toegerekende vaste kosten ook meegenomen werden bleek het gewas suikerbiet meer op te brengen dan het gewas pootaardappel.

De teelt van C-bieten is niet aantrekkelijk, omdat de prijs van C-bieten aanzienlijk lager is dan die van quotumbieten; de teelt van tarwe levert meer op. Het geschatte areaal suikerbieten om het suikerquotum exact vol te produceren bleek echter een onzekerheid te vertonen; de standaardafwijking van het benodigde areaal was $\pm$ 10%.

In de einddiscussie werd geconcludeerd dat de doelstelling van het project bereikt was; beslissingen ten aanzien van N-beschikbaarheid, plantaantal en oogstdatum kunnen gelijktijdig (bijvoorbeeld als een soort gevoeligheidsanalyse in de winter voorafgaande aan de teelt) maar ook onafhankelijk van elkaar genomen worden als de niveaus van de andere beslissingen bekend zijn. Voor verbetering vatbaar zijn: 1) het suikergehalte; 2) de perceelsspecifieke potentiële opbrengst- en kwaliteitsniveaus, die tot dusverre gebaseerd zijn op regionale gemiddelden; 3) het aantal beslissingen die ondersteund worden. De invloeden van onder andere ras en managementvaardigheden zijn niet in de beschouwing meegenomen. Er is geen aandacht besteed aan de kwaliteit van de uitvoering van de beslissingen op bedrijfs- en perceelsniveau en ook het nemen en uitvoeren van overige beslissingen in de suikerbietenteelt zijn niet bestudeerd.

PIEteR kan toegepast worden bij beslissingsondersteuning op bedrijfs- en perceelsniveau, bij regionale en landelijke oogstvoorspellingen (voor de campagneplanning van de suikerindustrie), bij analyse van verschillen tussen actuele en potentiële opbrengsten (om groeilimiterende en -beperkende factoren op te sporen) en bij de evaluatie van teelttechnieken. PIEteR kan worden beschouwd als een basismodel voor 'normale' omstandigheden. Aanvullend onderzoek is nodig om bestaande modules te verbeteren en aanvullende modules te ontwikkelen voor andere dan standaardomstandigheden en -beslissingen. Onderzoek naar het suikergehalte, de potentiële niveaus voor wortel- en suikeropbrengst en (K + Na)- en α-amino-N-gehaltes en onderzoek aan de waterbalans- en tarramodules kunnen bijdragen tot verbetering van de huidige versie van het model. Aanvullende modules voor de invloeden van onkruiden, ziekten en plagen, beregening, ras, voorgaande gewassen, organische stikstofbemesting en de N-balans (voornamelijk als hulpmiddel om de N-verliezen naar beneden te brengen) kunnen nuttig zijn voor verbreding van de toepassingsmogelijkheden van het model. Als zowel de verwachte effecten van de voorgestelde verbeteringen op de kwaliteit van het beslissingsondersteunend systeem als het gemak waarmee ze in praktijk gebracht kunnen worden, worden bekeken, lijkt verbetering van de potentiële perceelsspecifieke niveaus van opbrengst- en kwaliteitsparameters de belangrijkste optie, gevolgd door aanvulling met modules voor onkruiden, ziekten en plagen, rasverschillen en voorgaande gewassen.

Voor toepassing in de praktijk moet de huidige versie van PIEteR gebruikersvriendelijk gemaakt worden, zodat meer potentiële gebruikers het model kunnen gebruiken zonder hulp van computerdeskundigen. De ontwikkeling van een expertsysteem als BETAKWIK, dat daadwerkelijk door telers gebruikt wordt, laat zien dat er voor een beslissingsondersteunend systeem als PIEteR een veelbelovende toekomst is.

Curriculum vitae

Albert Bene (Bert) Smit werd op 24 juli 1961 geboren op een landbouwbedrijf nabij Appingedam (Gr.). Na het behalen van het diploma Atheneum-B aan het Fivelcollege te Delfzijl begon hij in 1979 met een studie Landbouwplantenteelt aan de toenmalige Landbouw Hogeschool (later: Landbouwuniversiteit, LUW) te Wageningen. In de beginfase van zijn studie kwam de ziekte S.L.E. (systematische lupus erythematodes) aan het licht die hem enkele jaren studie-onderbreking en -vertraging opleverde. De studie kon desondanks in januari 1991 afgerond worden met als afstudeervakken Akkerbouw en Agrarische Bedrijfseconomie en met een onderzoeksstage Landbouwplantenteelt op het Volcani-Instituut in Israël.

Onmiddellijk na zijn afstuderen werd hij toegevoegd onderzoeker bij de vakgroep Agrarische Bedrijfseconomie van de LUW op een tweetal projecten: 1) 'Toekomstperspectieven Oldambt en Veenkoloniën', in opdracht van de Provincies Groningen en Drenthe, en 2) 'De toekomst van de fabrieksaardappelteelt in de Veenkoloniën', in opdracht van coöperatie AVEBE te Veendam. In de periode 15 januari 1992 t/m 15 februari 1996 was hij (met één maand verlenging) assistent in opleiding (AIO) op het onderzoek dat in dit proefschrift beschreven is. Hij was in dienst van de vakgroepen Agronomie en Agrarische Bedrijfseconomie, terwijl het Instituut voor Rationele Suikerproduktie (IRS) in Bergen op Zoom het onderzoek grotendeels financierde. Vanaf 15 februari tot 1 oktober 1996 werkte hij deels als gastmedewerker en deels als toegevoegd onderzoeker (vanaf 1 april) bij de vakgroep Agrarische Bedrijfseconomie aan de afronding van het proefschrift en aan verbetering van het oogsprognosemodel SUMO van het IRS, in samenwerking met de Nederlandse suikerindustrie.

Vanaf 15 november 1996 hoopt de auteur gedurende twee jaren als post-doc voor de vakgroep Agrarische Bedrijfseconomie te werken aan een project getiteld 'Ontwikkeling en toepassing van een methodiek voor een produktie-ecologische en sociaal-economische verkenning van opties voor duurzame produktiesystemen in de akkerbouw'. Dit betreft een gemeenschappelijk project van de C.T. de Wit Onderzoekschool Produktie Ecologie en het Mansholtinstituut, waarin respectievelijk de participerende vakgroepen Bodemkunde en Geologie en Agrarische Bedrijfseconomie deelnemen.