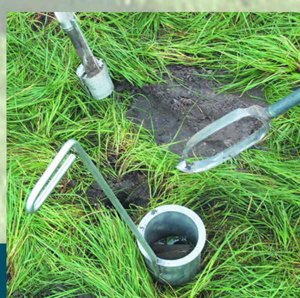
Sturen op Nitraat

# A base-line survey of indicators for nitrate loss from cropping and farming systems in the Netherlands

H.F.M. ten Berge (Ed.)

Reeks Sturen op Nitraat 2

A base-line survey of indicators for nitrate loss from cropping and farming systems in the Netherlands Reeks Sturen op Nitraat 2

PLANT RESEARCH INTERNATIONAL

# A review of potential indicators for nitrate loss from cropping and farming systems in the Netherlands

H.F.M. ten Berge (Editor)

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# The 'Sturen op Nitraat' Report Series

The report series 'Sturen op Nitraat' documents the results obtained in the project 'Sturen op nitraat' ('Focus on Nitrate'). The project was commissioned by the Dutch Ministry of Agriculture, Nature Management and Fisheries, and the Ministry of Housing, Spatial Planning and the Environment. Its chief aim is to develop a practical proxy for the nitrate load on groundwater, to be used in monitoring as well as in guiding farm management.

The project is carried out by the following partners: Alterra Green World Research; Applied Research for Arable Farming and Field production of Vegetables (PPO); Research Institute for Animal Husbandry (PV); CLM Research and Advice Plc.; and Plant Research International B.V.

De serie 'Sturen op Nitraat' bundelt de onderzoeksresultaten behaald in het kader van het gelijknamig project. Het project wordt uitgevoerd in opdracht van het Ministerie van Landbouw, Natuurbeheer en Visserij en het Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer. Doel is een handzame indicator voor de nitraatbelasting van grondwater te ontwikkelen, ten behoeve van zowel monitoring doeleinden als voor sturing in de landbouwpraktijk.

Het project wordt uitgevoerd door onderzoekspartners Alterra Research Instituut voor de Groene Ruimte, Praktijkonderzoek Plant en Omgeving (PPO); Praktijkonderzoek Veehouderij (PV); Centrum voor Landbouw en Milieu (CLM); en Plant Research International B.V.

# Preface

This report concludes the first phase of the project 'Focus on Nitrate' ('Sturen op Nitraat'). The goal of this phase was to explore existing information on nitrate loss from cropping and farming systems in the Netherlands. In particular, relations were sought between so-called candidate indicators for nitrates loss: farm N-surplus, field N-surplus, residual mineral N in soil, and nitrate concentration in shallow groundwater.

The study brings together many experimental data collected in the field of nitrate research over the past decades in the Netherlands, and includes new 'overall' analyses of these data by various approaches. In addition, simulation models are used to explore relations between candidate indicators, especially where field data are scarce.

This review should provide a background for the main project activity in 'Focus on Nitrate', which is to collect and interpret new field data through an extensive monitoring programme directed specifically at sandy soils in the Netherlands. The monitoring programme will establish a firm basis for assessing indicators for nitrate loss, and will show how local factors can be taken into account.

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# Samenvatting en conclusies

## Management samenvatting

Dit rapport sluit de explorative fase af van het project 'Sturen op Nitraat'. Doel van deze fase was het bijeenbrengen van bestaand materiaal (data, modellen) op het gebied van (potentiële) nitraat-emissie uit teelt- en bedrijfssystemen; en analyse van dit materiaal teneinde reeds bij de aanvang van het monitoringprogramma zo goed mogelijk de relaties vast te stellen tussen enkele geselecteerde 'kandidaat-indicatoren' voor (potentiële) nitraat-emissie.

Deze 'kandidaat-indicatoren' zijn

i. het bedrijfsoverschot aan stikstof (N) volgens MINAS-systematiek of volgens de werkelijke bedrijfsbalans;
ii. het perceelsoverschot en gerelateerde grootheden zoals b.v. N-gift;
iii. de hoeveelheid residuaire minerale N in de bodem bij oogst of in het late najaar ($N_{min,H}$);
iv. de nitraatconcentratie in het bovenste grondwater

Voorliggende studie brengt vrijwel alle data bijeen die in de afgelopen 20-25 jaar in Nederland zijn verzameld op dit terrein, en heeft de gelegenheid geboden tot een grondige analyse van dit materiaal volgens eenzelfde systematiek. Hoewel delen van dit materiaal natuurlijk reeds eerder zijn geanalyseerd en gerapporteerd in diverse vormen, wordt daar niet systematisch naar verwezen. Wel zijn steeds de bronnen vermeld waaraan de oorspronkelijke data ontleend zijn.

Uit de studie komt naar voren dat op grond van het bestaande onderzoeksmateriaal geen zekere conclusies kunnen worden getrokken m.b.t. de geschiktheid van de onderscheiden indicatoren (perceelsoverschot en daaraan gerelateerde balanstermen; $N_{min,H}$; bedrijfsoverschot) als maatstaf voor de werkelijke nitraatbelasting van het grondwater, c.q. als instrument voor het nitraatbeleid op droge zandgronden en lössgronden. Weliswaar zijn goede verbanden tussen deze indicatoren onderling aantoonbaar, de vertaling naar nitraatbelasting van het grondwater (nitraatconcentratie in ondiep grondwater) is vooralsnog behept met grote onzekerheid. Daarom kan nog geen van de indicatoren definitief beoordeeld worden op zijn bruikbaarheid als schatter voor nitraatbelasting. [1]

Wel kan geconstateerd worden dat de weinige empirische relaties die er zijn, suggereren dat er in werkelijkheid een sterker verband tussen $N_{min,H}$ en nitraatconcentratie in grondwater of percolerend water bestaat dan we aantreffen in de simulatie-resultaten. Het project 'Sturen op Nitraat' is zèlf juist gericht op monitoring van zowel $N_{min}$ als nitraat in grondwater, zodat verwacht mag worden dat er binnen enkele jaren een steviger basis ligt voor het afleiden van empirische verbanden. Het explorative onderzoek heeft tegen die achtergrond scherp in beeld gebracht welke verbanden nader onderzoek c.q. monitoring behoeven.

## Toelichting op methoden en technieken van het explorative onderzoek

Verreweg het grootste deel van de data heeft betrekking op waarnemingen van residuaire minerale stikstof in de bodem bij oogst van het gewas ($N_{min,H}$), als functie van de N-gift. De relatie tussen deze twee grootheden kon daarom uitvoerig gedocumenteerd worden (Hoofdstukken 3,4,5). In een groot aantal experimenten werd ook de N opbrengst (opname in afgevoerd produkt) vastgesteld. Daardoor kon ook de relatie tussen $N_{min,H}$ en het perceelsoverschot (en meer complexe, daaraan gerelateerde termen uit de minerale-N balans op perceelsniveau) onderzocht worden (o.a. Hoofdstukken 3,4).

1 Dezelfde kanttekening kan per saldo geplaatst worden bij indicatoren die 'verder weg' liggen van het uiteindelijke doel, zoals stikstofgift uit dierlijke mest of veedichtheid.

De vele datasets zijn ook gebruikt om een indeling naar gewasgroepen te maken op basis van de bij normale teelt (adviesgift) op het moment van oogst te verwachten residuaire minerale stikstof in de bodem (Hoofdstuk 5).

Het project 'Sturen op Nitraat' voorziet erin om per 'cluster', zoals die in de onderzoeksregio's voorkomen, de relaties tussen indicatoren vast te stellen. Een 'cluster' is een specifieke combinatie van bodemtype, grondwatertrap (GT) en gewas. Door onvolledigheid van de historische databestanden was het echter niet mogelijk deze indeling naar clusters in de voorliggende desk studie te volgen. In veel datasets ontbreken zowel bodembeschrijving als informatie over de grondwatertrap. Hoewel een deel van deze informatie te achterhalen is, loont dat niet de moeite omdat het gehele databestand dan alsnog een belangrijk gebrek vertoont, namelijk dat data voor een bepaalde gewas-bodem-GT combinatie betrekking hebben op bijv. jaren 1985-1988, terwijl data voor een andere cluster verzameld zijn in een andere periode. De mogelijke effecten van 'jaar' en van 'cluster' op een te verklaren grootheid zijn daardoor niet van elkaar te scheiden. Slechts voor enkele gewassen was een onderscheid op basis van een grove bodemindeling (zand, klei, veen) mogelijk (Hoofdstukken 4,5).

De hoeveelheid residuaire minerale N die op het moment van oogst in de bodem wordt aangetroffen, ondergaat vervolgens modificaties door een aantal 'na-oogst' factoren waarvan sommige gewas-afhankelijk zijn. Het samenspel tussen deze factoren leidt tot een $N_{min}$-waarde in het late najaar, bijv. op 1 december, die de basis vormt voor uitspoeling in het winterseizoen. De belangrijkste van deze factoren zijn: het oogsttijdstip; de hoeveelheid N die na oogst uit gewasresten kan vrijkomen; de hoeveelheid N die nog door mineralisatie na oogst vrijkomt uit voorjaars-toegediende dierlijke mest en uit de organische-stof voorraad in de bodem (beide afhankelijk van neerslag, temperatuur en eigenschappen van mest en bodem); uitspoelingsverlies in het najaar (neerslag); evt. najaarstoediening van dierlijke mest; en 'last but not least' de inzet van vanggewassen en groenbemesters. De effecten van al deze factoren op de modificatie van $N_{min,H}$ vóór de winter zijn in de vorm van vuistregels gekwantificeerd in Hoofdstuk 6.

De analyse van gegevens m.b.t. grasland is gescheiden in:
a) analyse van oorspronkelijke data uit maaiproeven en daaruit afgeleide relaties tussen N-gift, perceelsoverschot of andere balanstermen enerzijds, en gemeten $N_{min,H}$ anderzijds (Hoofdstukken 3,4); en
b) analyse van de effecten van beweidingssystemen via urine-depositie bij weidegang (Hoofdstuk 7).

Laatstgenoemde analyse is uitgevoerd m.b.v. de modelcombinatie NURP-BBPR. Hoewel het in de bedoeling lag de rekenregels in dit model volledig consistent te maken met de resultaten gerapporteerd in Hoofdstukken 3 en 4, en de grondslagen voor de berekening van additionele opbouw van $N_{min,H}$ (t.g.v. urineplekken bij weidegang) up-to-date en expliciet te maken, is dat in het tijdsbestek van deze exploratieve studie niet mogelijk gebleken. Daarom is voor het berekenen van de effecten van beweiding gebruik gemaakt van NURP-BBPR zoals voorheen gedocumenteerd.

Voor het bepalen van de relaties tussen het bedrijfsoverschot en de diverse indicatoren op perceelsniveau zijn bij akkerbouw/vollegrondsgroententeelt en melkveehouderij onderscheiden wegen bewandeld. In de akkerbouw en vollegrondsgroententeelt (Hoofdstuk 9) is het bedrijfsoverschot vrijwel identiek aan de som van de overschotten op de respectievelijke percelen/gewassen. Voor een reeks van uiteenlopende bouwplannen kon daardoor - op grond van de in Hoofdstuk 5 afgeleide empirische relaties op gewasniveau en de vuistregels uit Hoofdstuk 6 voor na-oogst processen – het verband gelegd worden tussen het bedrijfsoverschot en de diverse onderliggende indicatoren op perceelsniveau.

In de melkveehouderij (Hoofdstuk 10) is de relatie tussen perceels- en bedrijfsoverschotten sterk afhankelijk van factoren als veebezetting en beweidingssysteem. Voor deze sector is gebruik gemaakt van modellen om de relaties tussen indicatoren vast te stellen, door een groot aantal bedrijfsconfiguraties ‘door te rekenen’. Het bedrijfsmodel BBPR is hiervoor ingezet, waarvan de milieu-component gebaseerd is op de biofysische relaties vastgelegd in NURP.

Om het verband te bepalen tussen residuaire minerale stikstof in de bodem ($N_{min}$) in het late najaar (hier is 1 december steeds als standaard gehanteerd) en de daadwerkelijke uitspoeling van nitraat – waarvoor de nitraatvracht over zekere diepte òf de nitraatconcentratie in het bovenste grondwater als maat wordt genomen – zijn slechts weinig goede metingen beschikbaar. Het beperkte materiaal dàt in Nederland beschikbaar is, is grotendeels samengebracht in dit rapport en dit geeft zowel voor akkerbouwgewassen als (gemaaid) grasland de indruk dat er een duidelijk verband bestaat tussen $N_{min}$ en nitraat-N-vracht c.q. de daaruit afgeleide nitraat-N-concentratie in grondwater. Overigens staat de helling (groter of kleiner dan 1:1) van dit verband niet op voorhand vast: enerzijds zijn er verliezen door bijv. denitrificatie in de ondergrond waardoor niet alle residuaire N wordt ‘teruggevonden’ in het grondwater; anderzijds leiden uitspoelingsverliezen in de zomer tot een lagere $N_{min,H}$ (bij oogst) of $N_{min}$ (op enig later tijdstip) terwijl zomerverliezen de hoeveelheid nitraat in het grondwater juist (kunnen) verhogen.

Omdat de experimentele basis voor een verband tussen beide grootheden smal is, en de data soms een niet goed begrepen ‘snelle stijging’ van de nitraatconcentratie bij lage $N_{min,H}$–waarden te zien geven, is voor het vaststellen van relaties gebruik gemaakt van simulatie, met behulp van het model ANIMO. Simulatieresultaten moeten in het algemeen met zekere reserve worden bezien. Dat geldt zeker voor de uitkomsten van complexe procesmodellen. Niettemin bieden die op dit moment het enige houvast, naast de beperkte waarnemingen.
De simulaties tonen een goede samenhang tussen $N_{min}$ in het najaar en de nitraatconcentratie in het ondiepe grondwater in het voorjaar, maar alléén wanneer het tijdstip en de diepte van de ‘bemonstering’ (van de simulatieresultaten) vrij gekozen mogen worden. In dat geval worden voor alle vier gesimuleerde ‘cases’ – te weten Ruurlo Gras, 1980-1984; Cranendonck Gras 1992-1994; Cranendonck Maïs, 1974-1982; en Vredepeel Maïs, 1990-1995; steeds $R^2$-waarden van ca. 0.90 gevonden voor de correlatie tussen $N_{min}$ en nitraatconcentratie in grondwater.

Die goede samenhang verdwijnt echter zodra voor tijdstip en diepte van de ‘bemonstering’ een tevoren vastgestelde combinatie wordt gebruikt: hier 1 december voor $N_{min}$ op diepten 0-60 cm (mais) en 0-100 cm (gras); en 1 april voor nitraat in de bovenste meter grondwater. De relatie verbetert niet sterk wanneer de nitraatvracht (op 1 m beneden maaiveld) wordt gebruikt i.p.v. de concentratie in grondwater.

Het ‘vast zetten’ van diepte en tijdstip waarop de simulatieresultaten worden ‘bemonsterd’ heeft in deze simulatie-exercitie niet tot doel om de geschiktheid van deze keuze (specifieke tijdstip-diepte combinatie) te evalueren, maar bootst in feite de willekeurigheid na van het bemonsteringstijdstip bij een werkelijke veldbemonstering in een monitoringprogramma; tevens wordt hiermee uitdrukking gegeven aan de onmogelijkheid om in een bemonsteringsprotocol op steeds wisselende voorgeschreven diepten te bemonsteren, in afhankelijkheid van lokale omstandigheden. Kortom, we moeten er rekening mee houden dat de ‘ruis’ die we vinden in de gezochte relaties bij ‘bemonstering’ van de simulatieresultaten op tevoren vastgestelde diepte en tijd, óók zal optreden bij werkelijke veldbemonstering.

Uit de simulaties blijkt (niet uitputtend weergegeven in dit rapport) dat deze ruis grotendeels veroorzaakt wordt door verschillen in omstandigheden die binnen een lokatie optreden tussen jaren. Deze verschillen worden meestal aangeduid met de term ‘weerjaarsvariatie’, omdat het weer (soms incl. grondwaterstanden) de enige factor is die verschilt tussen ‘gesimuleerde jaren’. In feite betreft het een serie interacties tussen processen in bodem, gewas en water die afhangen van het jaarlijks verloop van temperatuur, neerslag, en andere door het weer bepaalde productieomstandigheden. Deze leiden tot (werkelijke en gesimuleerde) variaties in opname, mineralisatie, N-vastlegging, N-uitspoeling en denitrificatie. Op zich zou variatie in deze omstandigheden niet noodzakelijkerwijs de relatie tussen

$N_{min}$ en nitraatconcentratie of –vracht behoeven te verstoren. Dat gebeurt echter wel, en de belangrijkste verklaring hiervoor is, volgens de uitgevoerde simulaties, dat nitraat zich als een 'golf' door de bodem en vervolgens in het grondwater naar diepere lagen verplaatst. Wáár de piek van de nitraatvracht zich op zeker moment bevindt, hangt af van het neerslagpatroon, vooral de omvang van het neerslagoverschot en het patroon van de neerwaartse waterstroom in de tijd. Zo is het dus mogelijk dat het N-overschot en $N_{min}$ goede indicatoren zijn voor de jaarlijkse nitraatbelasting van het grondwater, terwijl het toch moeilijk is via monitoring (of simulatie) een goed verband tussen deze variabelen aan te tonen. Deze problematiek is in het kader van 'Sturen op Nitraat' in een apart rapport bewerkt, ter onderbouwing van bemonsteringsprotocols. Het RIVM heeft een multiple-regressieprocedure ontwikkeld om gemeten nitraatwaarden in zekere mate te corrigeren voor jaarlijkse variaties in het neerslagpatroon. Deze procedure bleek niet direct hanteerbaar voor normalisatie van de hier gepresenteerde rekenresultaten, gezien de structuur van het simulatie-experiment. Toch werd een poging gedaan te corrigeren voor weerjaarsvariatie, door hetzij het gesimuleerde neerslagoverschot (periode 1 december tot 1 april), hetzij de grondwaterstand (op 1 april) als extra verklarende variabele in regressiemodellen toe te voegen. Deze termen blijken de correlatie tussen $N_{min}$ en de nitraatconcentratie in grondwater inderdaad significant te verhogen, maar de 'ruis' is ook na deze normalisatie dermate hoog dat de vertaling van $N_{min}$ naar nitraatconcentratie problematisch blijft, althans op grond van deze simulatieresultaten. Daarom wordt uitgekeken naar het beschikbaar komen, in 2001 en volgende jaren, van een bredere set gegevens als basis voor empirische relaties en ter verbetering van rekenmodellen.

## Conclusies

De belangrijkste conclusies die uit voorliggende studie naar voren treden zijn hieronder weergegeven. De Hoofdstukken 1 en 2 geven achtergrond en een theoretische grondslag voor dit onderzoek, en leiden niet tot conclusies die hier vermelding behoeven.

### Hoofdstuk 3

Voortbouwend op een balansconcept voor minerale N in de bodem geïntroduceerd in Hoofdstuk 2, worden in Hoofdstuk 3 enkele hypothesen getoetst op grond van datasets uit experimenten waarin naast $N_{min,H}$ ook andere grootheden werden gemeten. Deze zijn voor slechts een beperkt aantal gewassen beschikbaar. Hier zijn vooral data m.b.t. (gemaaid) gras en maïs geanalyseerd. De volgende conclusies worden getrokken:

- De basiswaarde $N_{minH,0}$ – dit is de bij oogst gemeten $N_{min,H}$ op onbemeste objecten – verklaart in sommige gewassen een groot deel van de variantie in $N_{min,H}$. Dit geldt in sterke mate voor maïs, waar $N_{minH,0}$ tot 80 kg N/ha kan bedragen, afhankelijk van het N-leverend vermogen van de bodem, zoals uitgedrukt in $U_0$, de N-opbrengst op deze zelfde onbemeste objecten. Informatie over $N_{minH,0}$ is in zekere mate substitueerbaar door de neerslagsom over het groeiseizoen.
- Op 'rijke' bodems zal maïs altijd met een vanggewas gecombineerd moeten worden, om de kans op hoge $N_{minH,0}$ waarden te verkleinen.
- De 'terugwinning' van toegediende N door het gewas (geoogst produkt) is aanvankelijk een lineaire functie van de gift: de fractie van de werkzame dosis die in geoogst produkt wordt teruggevonden is constant. Op dit gift-traject wordt geen accumulatie van $N_{min,H}$ gevonden, ondanks dat de terugwinningsfractie ('recovery') meestal slechts 0.5 tot 0.8 bedraagt.
- In vrijwel alle N-trappenproeven kan een zgn. kritische N-gift aangeduid worden: bij giften daarboven gaat de terugwinningsfractie dalen. Het is pas vanaf deze N-gift dat $N_{min,H}$ gaat stijgen boven de basiswaarde $N_{minH,0}$; de gewasopbrengst (biomassa droge stof) bedraagt bij deze gift meestal ca 90% van de haalbare opbrengst.

- Deze stijging vertoont i.h.a. een verloop dat m.b.v. een kwadratische of expo-lineaire vergelijking goed beschreven kan worden; in sommige (gras, mais) gewassen kan dit verloop ook redelijk voorspeld worden uit ‘onafhankelijke’ gewaskenmerken (nl. de parameters van het QUADMOD model).
- In gras en maïs kan tot 75% van de variantie in $N_{min,H}$ verklaard worden uit N-gift, $N_{minH,0}$ en zomerneerslag; diverse vormen van regressievergelijkingen zijn hiervoor geschikt.
- Zowel het verschil tussen werkelijke en kritische N-gift ($A$-$A_{crit}$), als het N-overschot op perceelsniveau ($A$-$U$) kunnen gebruikt worden als schatter voor $N_{min,H}$; Beide zijn echter behept met een moeilijkheid, namelijk dat dan bij toepassing in de praktijk de lokale waarde van resp. de kritische gift ($A_{crit}$) en de werkelijke opname ($U$) geschat moeten worden bij zekere waarde van de gift ($A$).
- De voorspelfout van een getest expo-lineair model voor $N_{min,H}$ als functie van ($A$-$A_{crit}$) is kleiner dan van een lineair overschotmodel, zowel in gras als in mais. Toch moet ook in dit expo-lineaire model steeds rekening gehouden worden met mogelijke afwijkingen (t.o.v. van de verwachte waarde) van ± 30-45 kg N/ha voor zowel gras als maïs (90% interval). Voor het overschotmodel geldt een fout van ca 60 (maïs) à 75 (gras) kg N/ha (90% interval).
- Bij gebruik van perceelsoverschot als regressor (lees: indicator) moet rekening worden gehouden met een verschuiving op lange termijn van het verband tussen $N_{min,H}$ en deze regressor, omdat de N-levering uit de bodem zich op den duur aanpast aan het overschot. Zo’n verschuiving treedt echter niet op in het verband tussen ($A$-$A_{crit}$) en $N_{min,H}$, waar het de waarde van $A_{crit}$ zèlf is die zich op termijn aanpast.

## Hoofdstuk 4

Terwijl de analyse van graslanddata in Hoofdstuk 3 betrekking had op alleen zandgronden, is in Hoofdstuk 4 een bredere dataset onder de loep genomen, waarin ook gegevens van klei- en veengronden aan de orde komen. Het betreft steeds maaiproeven. In deze analyse is meer aandacht geschonken aan de foutenstructuur binnen de datasets. Bovendien worden enkele additionele aspecten belicht. De volgende conclusies worden getrokken:

- De relatie tussen N-gift en de logarithme van de hoeveelheid residuaire N (0-100 cm) aangetroffen in de bodem bij de laatste snede ($N_{min,H}$) is goed te beschrijven door een kwadratisch verband. Het traject van N giften waarop de $N_{min,H}$-response nog gering is, is langer op (natte) veengronden dan op zandgronden. Dit is consistent met de procesbeschrijving in Hoofdstuk 2: op natte veengronden is de recovery (terugwinning) van toegediende N door het gewas immers lager en bijgevolg is de kritische N gift (die nodig is om tot zekere N-verzadiging van het gewas te komen) hoger.
- De voorspelfouten met dit model bedragen –25 tot +50 (klei-), -30 tot +100 (veen-) en –30 tot +75 (zandgronden) kg N/ha. Deze ranges gelden bij hoge N-doses en zijn afgeleid uit een relatief groot databestand. De ranges worden kleiner en zijn dan vergelijkbaar met die welke in Hoofdstuk 3 zijn gegeven, wanneer dezelfde datasets gebruikt worden als in Hoofdstuk 3 en bij hetzelfde neerslagniveau wordt geëvalueerd.
- Het basisniveau $N_{minH,0}$ dat men aantreft bij laatste snede in afwezigheid van N-bemesting gedurende het gehele seizoen, verschilt tussen enerzijds klei en zand en anderzijds veen. De veengronden vertonen relatief hoge $N_{minH,0}$-waarden, tot 50 à 60 kg N/ha. Door een verschuiving van deze basiswaarde verschuift i.h.a. de gehele responsecurve (van $N_{min,H}$ op N-gift) omhoog of omlaag, onafhankelijk van de N-gift.
- Het effect van regenval (neerslagsom over het gehele groeiseizoen) op $N_{min,H}$ hangt af van bodemtype (zand en klei *versus* veen) en van de N-gift. $N_{min,H}$ is positief gecorreleerd met regenval op veengronden, en negatief op zand en klei. Het effect van regenval op $N_{min,H}$ neemt toe met de hoogte van de mestgift. Op zand en klei is de basiswaarde $N_{minH,0}$ onafhankelijk van de neerslag, op veen is er een positive correlatie.
- De minerale N-voorraad in de bodem in het voorjaar, $N_{min,S}$, heeft een lichte invloed op de najaarswaarde $N_{min,H}$.

### Hoofdstuk 5

Een uitgebreid databestand (in beheer bij het Praktijkonderzoek Plant en Omgeving) met waarnemingen aan residuaire minerale N bij oogst van het gewas ($N_{min,H}$) in response op N-bemesting is geanalyseerd. Een groot aantal gewassen is in dit bestand opgenomen. De volgende conclusies worden getrokken:

- $N_{min,H}$ is in het algemeen positief gecorreleeerd met de N-gift. Bij eenzelfde N-gift tonen de verschillende gewassen grote verschillen in $N_{min,H}$ . Dit hangt o.a. samen met het uiteenlopend vermogen van de verschillende gewassen om N te absorberen.
- Ook wanneer elk gewas geteeld wordt bij de daarbij behorende (gewasspecifieke) adviesgift, treedt een sterke differentiatie op tussen 'veilige' en 'risico-volle' gewassen m.b.t. ophoping van $N_{min,H}$; deze worden op grond van de analyse in dit rapport aangegeven. Voor vrijwel alle in Nederland geteelde gewassen wordt de bij adviesgift verwachte waarde van $N_{min,H}$ gegeven (Zie tabellen in Hoofdstuk 5 en appendices).
- Het bodemtype (textuur) lijkt in het algemeen een gering effect te hebben op $N_{min,H}$; voor enkele gewassen kon het effect van bodemtype op $N_{min,H}$ worden gekwantificeerd;
- De neerslagsom over het groeiseizoen is in het algemeen negatief gecorreleerd met $N_{min,H}$
- De bemestingshistorie kan $N_{min,H}$ (sterk) beïnvloeden; dit komt vooral naar voren bij het gewas maïs; (zie ook Hoofdstuk 3)
- Gemiddeld over alle gewassen zal eens in de 10 jaar de verwachte $N_{min,H}$ waarde, zoals afgeleid voor adviesgift, met meer dan 75% overschreden worden.

### Hoofdstuk 6

- Metingen van $N_{min}$ bij de oogst van het gewas ($N_{min,H}$) worden wel eens 'snapshots' genoemd. Per definitie geven ze niet aan hoeveel van de residuaire N er uiteindelijk voor uitspoeling gedurende de winter beschikbaar zal zijn. Toch is er intussen voldoende kennis over na-oogst processen beschikbaar om de modificatie van $N_{min,H}$ tot een $N_{min}$-waarde aan het begin van het uitspoelingsseizoen te schatten. Deze kennis is samengevat in Hoofdstuk 6. Metingen van de hoeveelheid minerale N in de bodem bij oogst zijn daarom zeker geen 'loterij' en geven wel degelijk een basis voor bepaling van de potentiële nitraatuitspoeling.

### Hoofdstuk 7

De relaties tussen perceelsoverschot en $N_{min,H}$ onder beweiding op grasland zijn berekend met de modellen NURP en BBPR. De volgende conclusies zijn op deze berekeningen gebaseerd.

- Het beweidingssysteem en de stikstofgift hebben een grote invloed op het perceelsoverschot en $N_{min,H}$.
- Bij een gelijke stikstofgift neemt $N_{min,H}$ met ongeveer 7,5 kg N/ha toe per 100 grootvee-eenheid-weidedagen.
- Er is een sterke relatie tussen het perceelsoverschot en $N_{min,H}$. Bij een gelijk perceeloverschot is $N_{min,H}$ in geval van dag en nacht weiden zo'n 20 kg/ha hoger dan bij zomerstalvoedering.
- Vervroegen van de opstaldatum van 1 november tot 1 september leidt bij onbeperkt weiden (16 uur/dag) tot een daling van $N_{min,H}$ met ongeveer 25 kg N/ha en bij zeer beperkt weiden (4 uur/dag) tot een daling met ongeveer 5 kg N/ha.

### Hoofdstuk 8

Een modelstudie op basis van het model ANIMO vormde de grondslag voor een verkenning van de relatie tussen de hoeveelheid residuaire N in de bodem in het najaar, $N_{min}$, en de nitraatconcentratie in grondwater in het voorjaar. De conclusies zijn in het eerste deel van deze samenvatting uitvoerig behandeld, wegens hun relevantie voor de beoordeling van alle kandidaat-indicatoren voor nitraat in grondwater.

**Hoofdstuk 9**

De relaties tussen bedrijfsoverschot en onderliggende indicatoren in de open teelten werden vastgesteld op grond van een set van 24 bedrijfstypen die enerzijds een goede afspiegeling vormen van de praktijk op zand en löss, en anderzijds voldoende variatie in bouwplannen vertonen om de relatie tussen bedrijfsoverschot en andere indicatoren goed te kunnen vaststellen. De set omvat akkerbouwbedrijven en al dan niet gespecialiseerde vollegrondsgroentebedrijven, en varianten met zuiver kunstmest zowel als combinaties van varkensdrijfmest (voorjaar) met kunstmest. Perceelsoverschotten zijn steeds vastgesteld als areaal-gewogen gemiddelden over het gehele bedrijf. Zowel bedrijfs- als perceelsoverschotten zijn hier gebaseerd op totale N aanvoer, incl. niet werkzame N (in afwijking van de analyse in Hoofdstuk 3). Steeds werd bemesting volgens huidige adviesbasis verondersteld, en verder vormen de empirische relaties uit Hoofdstukken 5 en 6 de grondslag voor de analyse op bedrijfsniveau. Deze leidt tot de volgende conclusies:

- Een goed en lineair verband werd gevonden tussen werkelijk bedrijfsoverschot en MINAS overschot, op grond van deze studie voor 24 bouwplannen; het MINAS overschot ligt steeds ca 90 kg N/ha lager dan het totale bedrijfsoverschot. Oorzaken van dit verschil zijn o.a. N-depositie, en het verschil tussen werkelijke en (MINAS-) forfaitaire afvoer. Het gebruik van dierlijke mest beïnvloedt deze relatie niet.
- Bij gebruik van dierlijke mest nemen bedrijfs- en perceelsoverschotten toe wegens aanvoer van niet-werkzame N, maar dit heeft geen invloed op $N_{min,H}$. Hierdoor verschuift de relatie tussen overschot en $N_{min,H}$ zowel op perceels- als bedrijfsniveau. Gemiddeld bedraagt deze verschuiving in de geanalyseerde bedrijvenset enkele tientallen kg N/ha, afhankelijk van het aandeel dierlijke mest, en van de gewastypen (akkerbouw versus groenten).
- Afgezien van de ruis die ontstaat door een variabel aandeel dierlijke mest, werd een goed en vrijwel lineair verband gevonden tussen $N_{min,H}$ en het werkelijk N overschot op het bedrijf. Dat geldt in mindere mate voor het verband tussen $N_{min,H}$ en het MINAS overschot, wegens de grote variatie in werkelijke N-afvoer die tussen gewassen bestaat, en die in MINAS niet in beschouwing wordt genomen.
- Een goed lineair verband werd gevonden tussen $N_{min}$ bij oogst ($N_{min,H}$) en de waarden van $N_{min}$ op 1 december, zoals die voor de diverse bouwplannen werden berekend uit de vuistregels voor de na-oogst effecten (Hoofdstuk 6).
- Binnen de set van akkerbouw en vollegroentenbedrijven werd geen reden gevonden om de relaties tussen indicatoren te differentieren naar bedrijfstype (bouwplan). Wel zijn alle indicatorwaarden aanmerkelijk hoger in de groentenbedrijven dan in de akkerbouwbedrijven. Afhankelijk van de bouwplannen bedragen de verschillen: 40-100 kg N/ha (MINAS-overschot); 40-100 kg N/ha (werkelijk bedrijfsoverschot); 50-70 kg N/ha ($N_{min,H}$) en ca 50 kg N/ha ($N_{min}$ op 1 dec.). Vanzelfsprekend doet in alle bouwplannen variatie in het aandeel dierlijke mest de overschot-gebaseerde indicatoren verschuiven, en wel sterker naarmate de totale N-input groter is.
- Voor alle relaties vastgesteld in deze analyse op bedrijfsniveau geldt (evenals overigens voor de studies naar effecten van beweiding en bedrijfsconfiguratie in de melkveehouderij) dat de ‘ruis’ in de relaties die eerder werden vastgesteld op gewas/perceelsniveau (Hoofdstukken 3,4,5) ‘buiten beeld’ blijft, doordat steeds gewerkt is met de bij zekere N-gift verwachte indicatorwaarden ($N_{min,H}$; maar ook N-overschot omdat de werkelijke N-opbrengst bij eenzelfde gift varieert tussen jaren en lokaties; en ook de N-levering uit de bodem varieert). In werkelijkheid is die ruis echter onverminderd aanwezig. Een uitvoeriger onzekerheidsanalyse over de gehele ‘keten’ van indicatoren is daarom nodig, als basis voor een goede interpretatie van bij monitoring geregistreerde indicatorwaarden.

### Hoofdstuk 10

Een modelstudie gebaseerd op een combinatie van de programma's BBPR-NURP werd uitgevoerd op basis van een set van 80 bedrijfsconfiguraties, allen met een melkquotum van 500.000 kg, een productie per melkkoe van 8000 kg melk/j , een vervangingspercentage van 30% en voeding en bemesting volgens de huidige adviezen. Gevarieerd werden het bodemtype, het melkquotum per ha, de N-gift op grasland, het aandeel maïs in het bedrijfsareaal, het aandeel grasland dat alleen gemaaid wordt, en het beweidingssysteem. De overschotten werden steeds gebaseerd op totale N aanvoer, incl. niet-werkzame N. Op grond van de simulaties worden de volgende conclusies getrokken:

- Het N-overschot op bedrijfsniveau (werkelijk en volgens MINAS) vertoont een goed lineair verband met de N-overschotten op resp. beweid grasland (helling ca 1), gemaaid grasland (helling ca 0.5), en maisland (zeer kleine helling bij gehanteerde uitgangspunten). De bandbreedte is steeds ±25 kg in perceelsoverschot. Wel ligt de absolute waarde van het MINAS overschot 60-75 kg N/ha lager dan het werkelijk overschot (doordat MINAS depositie en strooisel niet in rekening brengt en de diercorrectie toepast).
- Het N-overschot op de beweide percelen wordt verhoogd door hoge N-gift, hoog maaipercentage, groot aandeel mais in het areaal, en lage bodemvruchtbaarheid
- Het N-overschot op de maaipercelen is hoog bij zomerstalvoedering van de gehele veestapel, hoge N bemesting, intensieve bedrijfsvoering, en lage bodemvruchtbaarheid.
- Doordat in de gebruikte versie van BBPR/NURP weinig variatie mogelijk is m.b.t. teeltwijzen van maïs, vertonen de uitkomsten voor maïsland nauwelijks een invloed van het perceelsoverschot op $N_{min,H}$. Het model behoeft nadere verfijning om dit te corrigeren. Verder laten de berekeningen een lichte invloed zien van het perceelsoverschot op $N_{min,H}$ in gemaaid grasland; en een relatief sterke invloed op $N_{min,H}$ in beweid grasland. Toch wordt ook hier maar ca 20% van het perceels-N-overschot als $N_{min,H}$ teruggevonden.
- Bij eenzelfde bedrijfsoverschot werden uiteenlopende $N_{min,H}$ waarden berekend (bandbreedte van 30-40 kg/ha), afhankelijk van de bedrijfsconfiguratie. Zo kan een bedrijfsoverschot van 175 kg N/ha gepaard gaan met een $N_{min,H}$ waarde van 45 tot 75 kg/ha (areaal-gewogen gemiddelde over alle grondgebruiksvormen in het bedrijf).
- Zie ook laatste kanttekening bij Hoofdstuk 9. Net als dáár geldt ook voor de relaties in Hoofdstuk 10 dat ze gebaseerd zijn op verwachte indicatorwaarden, en dat geheel voorbij gegaan wordt aan variatie ('ruis') die in werkelijkheid steeds bestaat rond elk verband tussen twee indicatoren.

# Summary and conclusions

## Management summary

This report concludes the exploratory phase of the project 'Focus on Nitrate' ('Sturen op Nitraat'). This phase was intended to collect existing material (data, models) concerning (potential) nitrate losses from cropping and farming systems, and to analyse this material to assess relationships between some selected 'candidate indicators' for (potential) nitrate losses. The exploratory phase is followed by an extensive monitoring programme focussed on nitrate leaching from sandy soils in the Netherlands.

The 'candidate indicators' are:
(i) farm nitrogen (N) surplus according to the MINAS system (the Dutch mineral accounting system that farmers have to comply with) or according to the total farm balance;
(ii) field surplus and related variables such as, e.g., N application rate;
(iii) amount of residual mineral N in the soil at harvest or in late autumn ($N_{min,H}$);
(iv) nitrate concentration in the upper groundwater.

This study brings together virtually all data that have been collected over the last 20-25 years in the Netherlands in this area, and has offered the opportunity for a thorough 'overall' analysis of this material. Although parts of this material have of course already been analysed and reported before in various forms, no systematic reference is made to such reports. The sources from which the original data were obtained, however, are always reported here.

The study shows that the existing material allows no firm conclusions to be drawn about the suitability of the different indicators (field surplus and related balance terms; $N_{min,H}$ and farm surplus) as a measure of the actual nitrate load on groundwater, i.e. as an instrument to be used in the frame of the nitrate policy for dry sandy soils and loess soils. Although good relationships between several of these indicators can be shown, the conversion to nitrate load on groundwater (or nitrate concentration in shallow groundwater) still holds large uncertainties. This means that none of the selected indicators can now be definitely assessed for its suitability as an estimator of the nitrate load.[2]

It can, however, be said that the few empirical data that do exist, suggest that there is actually a stronger correlation between nitrate and $N_{min,H}$ than indicated by simulations in this report. In addition, 'Focus on Nitrate' itself is precisely aimed at monitoring of $N_{min}$ in soils as well as nitrate in groundwater, so that a more solid basis for the derivation of empirical relationships may be expected soon. The exploratory research reported here has, against this background, clearly shown which relationships need further study and/or monitoring.

## Methods and techniques of the exploratory research

By far the largest part of available data concerns observations of residual mineral nitrogen in the soil at crop harvest ($N_{min,H}$), as a function of the N dose. This enabled extensive documentation of the relationship between these two variables (Chapters 3, 4, 5). N yield (uptake in removed product) was also recorded in a large number of experiments so that the relationship between $N_{min,H}$ and field surplus (and more complex related terms of the mineral N balance at field level) could also be studied (Chapter 3).

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2 The same remark can be made for indicators further removed from the ultimate goal, such as amount of nitrogen applied via animal manure, or the stocking density.

The many data sets have also been used for a classification of crops into groups according to the amount of residual mineral N to be expected in the soil profile at the moment of harvest, under standard recommended practice (N dose) (Chapter 5).

The envisaged monitoring programme in 'Focus on Nitrate' aims to establish relationships between indicators per 'cluster' as these are found in the studied regions. A 'cluster' is a specific combination of soil type, groundwater level (GT) and crop. Due to incompleteness of the historical data sets, however, it was impossible to follow this classification according to clusters as a basis for the present analyses. Soil description as well as information on groundwater level are lacking in many of the existing data sets. Although part of this information can be retrieved, this is not worthwhile because the total data set would then still show a major shortcoming, i.e., the data for a certain crop-soil-GT combination would relate to, for example, the years 1985-1988, whereas the data for another cluster had been collected in a different period. This means that the possible effects of the factors 'year' and 'cluster' on a variable can not be distinguished. A distinction on the basis of a broad soil classification (sand, clay, peat) was, however, possible for some crops (Chapters 4, 5).

The amount of residual mineral N found in the soil at the moment of harvest is subsequently modified by a number of 'post harvest' factors, some of which are crop-specific. The combined action of these factors leads to an $N_{min}$ value in late autumn, e.g., on 1 December, which forms the basis for leaching during the winter season. The most important of these factors are: time of harvest, the amount of N released by crop residues after harvest, the amount of N still released by post-harvest mineralisation from spring-applied animal manure and from the organic matter stock in the soil (both depending on precipitation, temperature and properties of manure and soil), leaching losses in autumn (precipitation), the possible autumn application of animal manure, and, last but not least, the use of catch crops and green manure crops. The effects of all these factors on the modification of $N_{min,H}$ before winter have – in the form of rules of thumb - been quantified in Chapter 6.

The analysis of the grassland data has been separated into:

(a) analysis of the original data from experiments with cut grass and the derived relationships between N dose, field surplus or other balance terms on the one hand, and measured $N_{min,H}$ on the other (Chapters 3, 4); and

(b) analysis of the effects of grazing systems via urine deposition during grazing (Chapter 7).

The last-mentioned analysis has been carried out by means of the model combination NURP-BBPR. Although it was intended to make the mathematical rules in this model fully consistent with the results found in (a) and to make the basis for calculating additional buildup of $N_{min,H}$ (as a result of urine patches during grazing) up-to-date and explicit, this was found to be impossible within the time span of this exploratory study. The earlier documented version of NUPR-BBPR was therefore used to calculate the effects of grazing on $N_{min,H}$.

Different methods have been used to establish the relationships between farm surplus and the various indicators at field level for arable farming (including field vegetable production) and for dairy farming. In arable farming and field vegetable production (Chapter 9) the farm surplus is virtually identical to the sum of the surpluses of the various fields/crops. This enabled the establishment of relations between farm surplus and the various underlying indicators at field level for a range of different crop rotations – on the basis of the empirical relationships at crop level derived in Chapter 5 and the rules of thumb for post-harvest processes from Chapter 6.

In dairy farming (Chapter 10), the relationships between field and farm surpluses are strongly dependent on factors such as stocking density and grazing system. For this sector, models have been used to establish the correlations between indicators by 'running' a large number a farm configurations. The NURP-BBPR farm model was used for this purpose.

Only a small number of good measurements are available to establish the relationship between residual mineral nitrogen in the soil ($N_{min}$) in late autumn (1 December was always taken as a standard) and actual nitrate leaching – expressed as the nitrate load over a certain depth or as the nitrate concentration in shallow groundwater (top 1 m of groundwater). The limited amount of material that is available in the Netherlands has been brought together in this report and gives, for arable crops as well as (cut) grassland, the impression that a clear relationship exists between $N_{min}$ and the nitrate-N load on groundwater or the nitrate N concentration in groundwater. The slope (larger or smaller than 1:1) of this relationship, however, is not clear beforehand: on the one hand there are losses due to, e.g., denitrification in the subsoil which mean that not all residual N is recovered in the groundwater; leaching losses in summer, on the other hand, lead to a lower $N_{min,H}$ (at harvest) or $N_{min}$ (at any later point in time) whereas summer losses (may) increase the amount of nitrate in groundwater.

Because the experimental basis for a relation between both variables is small, and the data sometimes show a not well understood 'rapid increase' of nitrate concentrations at low $N_{min,H}$ values, simulation by means of the ANIMO model has been used to establish relations. Simulation results should, generally, be considered with some caution. This is certainly true of the results from complex process modeling. They do constitute, however, a complement to the scarce data sets.
The simulations show a good correspondence between $N_{min}$ in autumn and the nitrate concentration of the shallow groundwater in spring, but only if the time and depth of 'sampling' (of the simulation results) may be chosen freely. In that case $R^2$ values of about 0.90 for the correlation between $N_{min}$ and nitrate concentration are found for all four simulated 'cases', i.e., Ruurlo Grass, 1980-1984; Cranendonck Grass 1992-1994; Cranendonck Maize, 1974-1982; and Vredepeel Maize, 1990-1995.

This good correspondence, however, disappears as soon as a predetermined combination of time and depth of 'sampling' is used: here 1 December for $N_{min}$ at depths 0-60 cm (maize) and 0-100 cm (grass); and 1 April, upper metre groundwater, for nitrate. The relationship does not improve significantly when the nitrate load (1 m below the soil surface) is used instead of the concentration in groundwater.

The objective of 'fixing' depth and time at which the simulation results are 'sampled' in this simulation exercise was not to evaluate the suitability of that particular choice (specific time-depth combination) but was meant to simulate the 'arbitrariness' of the sampling time in case of an actual monitoring programme; it also expresses the impossibility to sample at always varying prescribed depths in a sampling protocol, depending on local conditions. This means that we have to take account of the fact that the 'noise' found in the studied relationships when the simulation results are sampled at predetermined depth and time, will also occur in actual monitoring programmes.

The simulations show (not extensively presented in this report) that this noise is mainly caused by differences in conditions which occur within a location between years. These differences are usually referred to as 'weather year variation' because the weather (sometimes associated with groundwater levels) is the only factor that differs between 'simulated years'. In fact this concerns a series of interactions between processes in soil, crop and water, which depend on the annual course of temperature, precipitation, and other weather-determined production conditions. These lead to (actual and simulated) variations in uptake, mineralisation, N fixation, N leaching and denitrification. This variation in conditions as such would not necessarily have to disturb the relationship between $N_{min}$ and nitrate concentration or nitrate load. Yet, it does. The most important explanation for this is, according to the performed simulations, that nitrate peaks move as a 'wave' through the soil and subsequently into the groundwater. The location in the vertical sense of the nitrate peak at any given point in time depends on the precipitation pattern, especially the size of the precipitation surplus, and the pattern of the downward water flow over time, which is also affected by groundwater dynamics. This means that N surplus and $N_{min}$ may be good indicators of the annual nitrate load on groundwater whereas it is still difficult to show a good correspondence between these variables via monitoring (or simulation).
This issue is, in the context of 'Focus on Nitrate', dealt with in a separate report, to support sampling protocols. RIVM has developed a multiple regression procedure to normalize measured nitrate values,

based on annual variations in precipitation pattern. This procedure could, however, not directly be applied for normalisation of the simulation results presented here in view of the structure of the simulation experiment. It was nevertheless attempted to make an adjustment for weather year variation either by adding the simulated precipitation surplus (period 1 December to 1 April) or the groundwater level (on 1 April) as additional explanatory variable in regression models. These terms were indeed found to significantly increase the correlation between $N_{min}$ and the nitrate concentration in groundwater, but the 'noise' remaining after this normalisation was still so large that a translation of $N_{min}$ in soil to nitrate concentration in groundwater remains problematic, at least on the basis of these simulation results. A wider data set, as basis for empirical relationships and for the improvement of mathematical models, will soon be available from this project.

## Conclusions

The most important conclusions that can be drawn from this study are presented below. Chapters 1 and 2 present a background and theoretical basis of this study and do not lead to conclusions that need to be mentioned here.

### Chapter 3

Based on a balance concept for mineral N in the soil introduced in Chapter 2, a number of hypotheses are tested against experimental data. The required observations are, however, only available for a limited number of crops; the data that were analysed mainly concern (cut) grass and silage maize. The following conclusions are drawn:

- The basic value $N_{minH,0}$ – this is $N_{min,H}$ measured at harvest on unfertilised plots – explains a large part of the variation in $N_{min,H}$ for some crops. This is certainly true for maize, where $N_{minH,0}$ may amount up to 80 kg N/ha, depending on the N supplying capacity of the soil, as expressed in $U_0$, the N yield on the same unfertilised plots. Information on $N_{minH,0}$ can, to a certain extent, be substituted by the precipitation sum over the growing season to explain variations in $N_{min,H}$.
- On 'rich' soils, maize will always have to be combined with a catch crop to reduce the chance of high $N_{minH,0}$ values.
- Upto relatively high N doses, the 'recovery' of applied N by the crop (harvested product) is a linear function of the applied dose: the fraction of the effective dose recovered in the harvested product is constant. No accumulation of $N_{min,H}$ is found over this range of doses, despite recoveries of usually between only 0.5 and 0.8.
- A so-called critical N dose can be indicated in virtually all N dose experiments: by definition, the recovery decreases at doses exceeding this critical level. It appears that $N_{min,H}$ only exceeds the basic value $N_{minH,0}$ at doses higher than this critical dose; crop yield (biomass dry matter) at this dose is usually about 90% of the attainable yield.
- Generally, a quadratic or expo-linear equation gives a good description of the course of this increase in $N_{min,H}$; in some crops (grass, maize) this course can also be predicted reasonably well from 'independent' crop characteristics (i.e., the parameters of the QUADMOD model).
- In grass and maize, up to 75% of the variation in $N_{min,H}$ can be explained by N dose, $N_{minH,0}$ and summer precipitation, for which various forms of regression equations are suitable.
- The difference between actual and critical N dose ($A$-$A_{crit}$) as well as the N surplus at field level ($A$-$U$) can be used to estimate $N_{min,H}$. The problem with both, however, is that for practical applications, the local value of the critical dose ($A_{crit}$) or the actual uptake ($U$), respectively, must be estimated.
- The prediction error of the tested expo-linear model for $N_{min,H}$ as a function of ($A$-$A_{crit}$) is smaller than that of the linear surplus model, in grass as well as in maize. In this expo-linear model, deviations (in comparison with the expected value) of 30-45 kg N/ha (90% interval) are to be

expected. For the surplus model, the 90% error margins are 60 (maize) and 75 (gras) kg N/ha, respectively.
- When using field surplus as regressor (read: indicator), a long term drift in the relation between $N_{min,H}$ and this regressor should be taken into account because the N supply from the soil gradually adjusts to the surplus. Such a drift does not occur in the relation between ($A$-$A_{crit}$) and $N_{min,H}$, because the value of $A_{crit}$ itself is adjusted in the long run.

### Chapter 4

While the analysis of grassland data in Chapter 3 only concerns sandy soils, a broader data set is considered in Chapter 4, which also includes data from clay and peat soils. In this chapter, more attention is paid to the error structure within data sets while some additional aspects are considered. The following conclusions are drawn:

- The relation between N dose and amount of residual N (0-100 cm) found in the soil at the last cut ($N_{min,H}$) can well be described by a quadratic relation. The range of N doses at which the $N_{min,H}$ response is still limited, is longer on (wet) peat soils than on sandy soils. This is consistent with the process description in Chapter 2: on wet peat soils the recovery of the applied N by the crop is lower and consequently the critical N dose (required to achieve a certain N saturation of the crop) is higher.
- The basic $N_{minH,0}$ level found at the last cut in the absence of N fertilisation, differs between clay and sand on the one hand, and peat on the other. The peat soils show relatively high $N_{minH,0}$ values, up to 50 to 60 kg N/ha. Shifts of this basic value generally move the total response curve (of $N_{min,H}$ to N dose ) upward or downward, independent of the N dose.
- The effect of precipitation (precipitation sum over the total growing season) on $N_{min,H}$ depends on soil type (sand and clay *versus* peat) and on the N dose. $N_{min,H}$ shows a positive correlation with rainfall on peat soils, and a negative correlation on sand and clay. The effect of precipitation $N_{min,H}$ increases with the level of the N dose. On sand and clay, the basic value $N_{minH,0}$ is independent of precipitation; there is a positive correlation on peat.
- The mineral N stock in the soil in spring, $N_{min,S}$, has a slight effect on the autumn value $N_{min,H}$.

### Chapter 5

An extensive data set with observations of residual mineral N at crop harvest ($N_{min,H}$) in response to N doses has been analysed; this data set includes a large number of crops. The following conclusions are drawn::

- $N_{min,H}$ is generally positively correlated with N dose. Different crops show large differences in $N_{min,H}$ at the same N dose. This is the result of factors such as different crops having different N absorption capacities.
- Even when each crop is grown at the standard recommended crop-specific N dose, there is a strong differentiation between 'safe' and 'risky' crops in as far as nitrate leaching is concerned; these are specified in this report. The $N_{min,H}$ value expected at the recommended dose is given for virtually all crops grown in the Netherlands (see Tables in Chapter 5 and Appendices).
- Generally, soil type (texture) seems to have a slight effect on $N_{min,H}$; this effect could be quantified for some crops only.
- The precipitation sum over the growing season generally shows a negative correlation with $N_{min,H}$.
- Fertilisation history may (strongly) affect $N_{min,H}$; this becomes particularly apparent in maize (see also Chapter 3).
- The expected $N_{min,H}$ value for a crop, as determined at the recommended N dose, will be exceeded by more than 75% once in every ten years (This is an average over all crops).

**Chapter 6**

- $N_{min}$ measurements at crop harvest ($N_{min,H}$) are sometimes called 'snapshots'. By definition, they do not indicate how much of the residual N will finally be available for leaching during winter. Recently, however, sufficient information has become available about post-harvest processes to quantigy the modification of $N_{min,H}$ into an $N_{min}$ value at the start of the leaching season. This knowledge is summarised in Chapter 6. Measurements of the amount of mineral N in the soil at harvest should therefore no longer be regarded as a 'lottery' and they certainly provide a basis for the determination of potential nitrate leaching.

**Chapter 7**

The correlations between field surplus and $N_{min,H}$ under grazing conditions on grassland were calculated with the models NURP and BBPR. The following conclusions are based on these calculations.

- The grazing system and nitrogen doses have a strong effect on the field surplus and on $N_{min,H}$.
- At the same nitrogen dose, $N_{min,H}$ increases by about 7.5 kg N/ha per 100 'livestock unit grazing days'.
- There is a strong correlation between field surplus and $N_{min,H}$. At the same field surplus, $N_{min,H}$ is about 20 kg/ha higher in case of day and night grazing than in case of 'summer feeding indoors'.
- Advancing the stabling date from 1 November to 1 September does, in case of unrestricted grazing (16 hours/day), lead to a decrease in $N_{min,H}$ of about 25 kg N/ha; and in case of very restricted grazing (4 hours/day) to a decrease of about 5 kg N/ha.

**Chapter 8**

A model study based the ANIMO model formed the basis for an exploration of the relation between the amount of residual N in the soil in autumn, $N_{min}$, and the nitrate concentration in groundwater in spring. The conclusions are discussed extensively in the first part of this summary, in view of their relevance for an assessment of all candidate indicators studied here.

**Chapter 9**

The relationships between farm surplus and underlying indicators for open field crops were established on the basis of a set of 24 farm types, which on the one hand gives a good representation of commercial farming on sand and loess in the Netherlands, and on the other hand shows sufficient variation in crop rotation to enable a good establishment of the relations between farm surplus and other indicators. The set includes arable farms and (specialised) farms with field vegetable production, and variants with mineral fertiliser alone as well as combinations of pig slurry (spring) with mineral fertiliser. Field surpluses were always calculated as area-weighted averages over the total farm; farm as well as field surpluses are based on total N input, including ineffective N (in contrast to Chapter 3). N rates were in accordance with the current recommendations and the empirical relations found in Chapters 5 and 6 were used as the basis for the analysis at the whole-farm level. This leads to the following conclusions:

- A good and linear correlation between actual farm N surplus and MINAS N surplus was found on the basis of this study with 24 crop rotations; the MINAS surplus was about 90 kg N/ha lower than the total farm surplus. Causes of these differences are factors such as N deposition, and the difference between actual and fixed (MINAS) N offtake. The use of animal manures does not affect this relation.
- The use of animal manure increases farm and field surpluses due to the supply of ineffective N, but this has no effect on $N_{min,H}$. This results in a shift of the relation between surplus and $N_{min,H,}$, at field as well as farm level. This shift amounts to some tens of kgs N/ha in the analysed farm sets, depending on the proportion of animal manure and crop types (arable versus vegetables).

- Apart from the ‘noise’ caused by a variable proportion of animal manure, a good and almost linear relation was found between $N_{min,H}$ and the actual N surplus on the farm. This is to a lesser extent true of the relation between $N_{min,H}$ and the MINAS surplus, due to the large variation in actual N offtake that exists between crops, and which is not taken into account in MINAS.
- A good linear relation was found between $N_{min}$ at harvest ($N_{min,H}$) and the values for $N_{min}$ on 1 December, as calculated for the various crop rotations by using the rules of thumb for the post-harvest effects given in Chapter 6.
- Within the total set of arable and field vegetable farms, no reasons were found to differentiate the relationships between indicators according to farm types (crop rotation). All indicator values on field vegetable farms are, however, considerably higher than on the arable farms; depending on the crop rotations, the differences amount to: 40-100 kg N/ha (MINAS surplus); 40-100 kg N/ha (actual farm surplus); 50-70 kg N/ha ($N_{min,H}$) and about 50 kg N/ha ($N_{min}$ on 1 December). Variation in the proportion of animal manure does, in all crop rotations, cause a shift in the surplus-based indicators, which increases with increasing total N input.
- It is true of all relations established in this analysis at farm level (and incidentally also for the studies into the effects of grazing and farm configuration in dairy farming (as reported in Chapters 7 and 10) that the earlier observed ‘noise’ in the relations at crop/field level (Chapters 3, 4, 5) does not ‘show up’. This is because only expected values (averages) of the respective indicators were used in these farm-level studies of Chapters 7, 9 and 10. In actual fact, however, this noise is always fully present. A more extensive error analysis over the total ‘chain’ of indicators is therefore required as basis for a sound interpretation of indicator values registered during monitoring.

## Chapter 10

A model study based on the BBPR-NURP models was carried out using a set of 80 farm configurations, all with an annual milk quota of 500,000 kg, a production per dairy cow of 8000 kg milk/year, a replacement percentage of 30% and feeding and manuring in compliance with current recommendations. Soil type, milk quota per ha, N dose on grassland, the proportion of maize in the farm acreage, the proportion grassland that is only used for cutting, and the grazing system were varied. The surpluses were always based on total N supply, including ineffective N. The following conclusions are drawn on the basis of the simulations:

- The N surplus at farm level (both actual and MINAS surplus) shows a good linear relation with the N surpluses on grazed grassland (slope of about 1), cut grassland (slope of about 0.5), and maize land (very small slope). The band width is about 25 kg N/ha in field surplus. The absolute value of the MINAS surplus is 60-75 kg N/ha lower than the actual surplus.
- The N surplus on grazed fields is increased by high N doses, high mowing percentage, large proportion of maize in the crop plan, and low soil fertility.
- The N surplus on cut grass is high for ‘summer stable feeding’ of the total herd, high N fertilisation, intensive farm management, and low soil fertility.
- Because the version of BBPR/NURP that has been used allows little variation in maize cropping methods, the results for maize land hardly show an effect of field surplus on $N_{min,H}$. This is an artefact. The model needs further refinement to rectify this. Furthermore, the calculations show a slight influence of field surplus on $N_{min,H}$ in cut grassland, and a relatively strong influence on $N_{min,H}$ in grazed grassland. Yet even here, only about 20% of the field N surplus is recovered as $N_{min,H}$.
- Different $N_{min,H}$ values (band width 30-40 kg/ha) were calculated at the same farm surplus, depending on the farm configuration. A farm surplus of, e.g., 175 kg N/ha may give an $N_{min,H}$ value of 45 to 75 kg/ha (area-weighted farm average).
- As in Chapter 9, the relations in Chapter 10 are based on expected indicator values, and the variation (‘noise’) that in fact exists in reality around each relation between two indicators is ignored in these simulated results (See last remark Chapter 9, above).

# 1. Introduction

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## 1.1 Background

Agriculture is the major contributor to nitrate contamination of groundwater (Prins *et al.*, 1988; Strebel *et al.*, 1989; Fraters *et al.*, 1998). In the European Union this problem is addressed by the Nitrate Directive (Anonymous, 1991). Governments of all member states have the obligation to reduce this emission from agriculture by action and monitoring programmes. The ultimate goal of these programmes, the reduction in nitrate concentration to a value below 50 mg litre$^{-1}$ water, needs translation into yardsticks. Subsequently, these yardsticks must be linked to threshold values. Selection of a yardstick is generally based on the following criteria: 1) measurability and accuracy in relation to the costs involved, 2) responsiveness to (changed) management of individuals, and 3) effectiveness in terms of the ultimate goal.

Various yardsticks for the assessment of nitrate emissions to groundwater have been proposed. Figure 1.1 shows that yardsticks differ in remoteness from the ultimate goal, yielding more or less uncertainty with respect to achievement of the ultimate goal. Yardsticks also differ in spatial scale, reflecting allowance for spatial averaging. Perpendicular to Figure 1.1, an additional time axis can be imagined, reflecting the allowance for temporal averaging. Yardsticks can be put into a hierarchy reflecting that each yardstick is a means to an overlying goal.

The nitrate concentration of groundwater at regional scale (upper left hand corner of Figure 1.1) expresses the ultimate goal itself, but its value can hardly be related to (changed) management of an individual farmer and vice versa. Input in nitrogen (N) via animal manure represents an alternative yardstick. This yardstick has been selected by the European Commission and its threshold value has been set at 170 kg N ha$^{-1}$ year$^{-1}$. The application rate of manure N is undoubtedly responsive to modifications in management (i.e. by exporting manure to another farm or by acquiring land) and can be assessed relatively easily given its relation with animal density. However, the 'N input via manure' and 'animal density' in particular have a relatively weak relationship with the ultimate goal due to numerous interfering factors, such as variable N excretion per animal within livestock categories, level and composition of external inputs, husbandry techniques and set-up of the farm (grazing, composition of rations, housing, manure storage and application, crop rotation, etc.). Hence, it is a means-oriented regulation with an uncertain effect on the ultimate goal (Willems *et al.*, 2000; Schröder *et al.*, 2001).

N surpluses as determined by a balance of inputs and outputs represent an alternative yardstick (Oenema *et al.*, 1997; Neeteson, 2000; Anonymous, 2001, Schröder *et al.*, 2001). They can be established at the farm level (farm gate balance) and that the field level (field balance). In between the 'field balance' and the 'nitrate concentration of (upper) groundwater' another yardstick is represented by the supply of soil mineral N at the end of the growing season (Prins *et al.*, 1988; Neeteson, 1994; Schröder *et al.*, 1996; 1998). 'Balances' and 'soil mineral N residues' occupy an intermediate position between the goal-oriented yardstick 'nitrate concentration in groundwater' and the means-oriented yardsticks 'N input via manure' and 'livestock density'.

The performance of the various yardsticks in terms of the suggested criteria is poorly quantified. Hence, an extensive research and monitoring program was initiated in The Netherlands at the end of 2000. Within the framework of this program called 'Sturen op Nitraat', a limited number of yardsticks will be evaluated. This report reviews the sources of variation of residual soil mineral N in arable and livestock farming systems. In addition to that the relation of this yardstick with others such as the N surplus and the nitrate concentration in upper groundwater, is addressed.

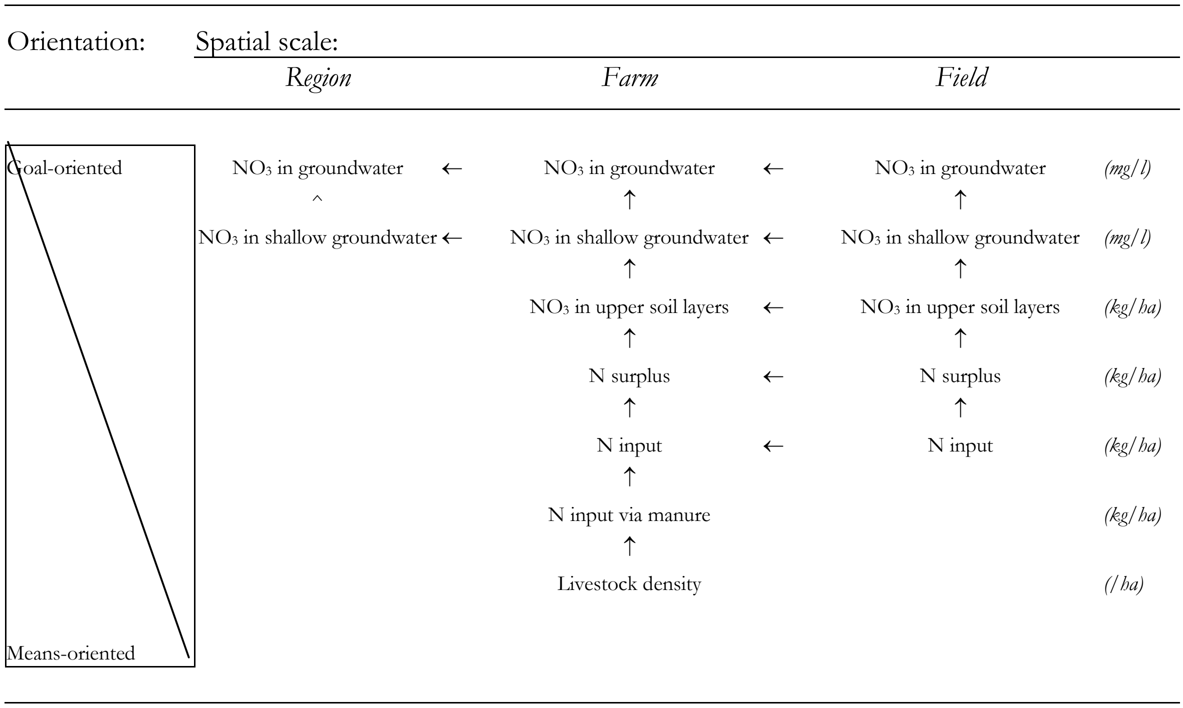


*Figure 1.1.* *Hierarchy of yardsticks for the assessment of N-emissions to groundwater and spatial scale at which they are operating (Schröder et al., 2002).*

## 1.2 N balance processes and related structure of the report

The amount of residual soil mineral nitrogen (N) at the time of crop harvest, $N_{min,H}$ (kg N ha$^{-1}$) can be written as the result of a mineral N balance accounting for all relevant processes operating during the growing season:

$$N_{min,H} = N_{min,S} + M_{net} + D + F + A - U - U_{CR} - \Sigma L_i \qquad 1.1$$

where (alle terms in kg N ha$^{-1}$):

| | |
|---|---|
| $N_{min,S}$ | the amount of mineral soil N at the start of the season (Spring time) |
| $M_{net}$ | net mineralisation, defined for the current purpose as the amount of N liberated during the growing season from residues of the preceding crop, soil organic matter, and decomposing microbial biomass, *minus* the incorporation in new microbial biomass; |
| $D$ | deposition of ammonia-N from the atmosphere |
| $F$ | biological fixation of elementary N from the atmosphere |
| $A$ | applied effective N rate; this term is composed of mineral N dose plus the fraction of applied organic N that is mineralised in the course of the growing season in which it was applied |
| $U$ | N-yield in harvested crop products |
| $U_{CR}$ | N fixed in crop residues |
| $L_i$ | all N losses except microbial fixation (already accounted for in $M_{net}$) |

The net result of these processes is the amount of mineral N found in the soil profile at the time of crop harvest. Some processes continue to operate beyond the crop's harvest, such as mineralisation from soil organic matter and earlier applied manures. Others attain importance only after harvest, such as mineralisation from fresh crop residues. Further important post-harvest terms are the application of animal manures on the stubbles, but also the interception of mineral N by catch crops and green manures. The post-harvest processes change the amount of residual mineral soil N from $N_{min,H}$ to $N_{min}$ in late fall ($N_{min,LF}$), which may be either higher or lower than $N_{min,H}$. In this report we take December 1st as the reference date for $N_{min,LF}$.

Figure 1.2 summarizes, for a year-around cycle, the main processes and their interrelations that affect the amount of mineral N in the soil profile.

While the post-harvest processes are treated in a separate chapter (Chapter 6), Chapters 3-5 will address the analysis of the amount of $N_{min}$ present in the soil at harvest, $N_{min,H}$. Chapter 2 presents a theoretical analysis, starting from the above balance equation, to provide a basis for developing and interpreting the various regression models evaluated in the later chapters.
Chapter 7 summarizes current knowledge about the effects of grazing on Nmin accumulation in grassland. introduces

For the translation of the amount of $N_{min}$ in the soil profile in late autumn to a concentration of nitrate-N in shallow groundwater in the subsequent year, little empirical basis exists today. This lack was one of the reasons for starting the current project 'Sturen op Nitraat', and to fill this gap is among its major goals. The explorative study reported here, however, aims to summarize existing information and this includes 'understanding' wrapped into simulation models. A dynamic model (ANIMO) was therefore used to generate 'synthetic data' of Nmin in the soil profile and nitrate in groundwater, thus providing a basis for deriving relations between these indicators. This material is presented in Chapter 8.

Chapter 9 (arable crops) and 10 (dairy farming) then aim to extrapolate the findings reported in earlier chapters, which all relate to the field level, into conclusions regarding indicators at whole-farm level, and their relations.

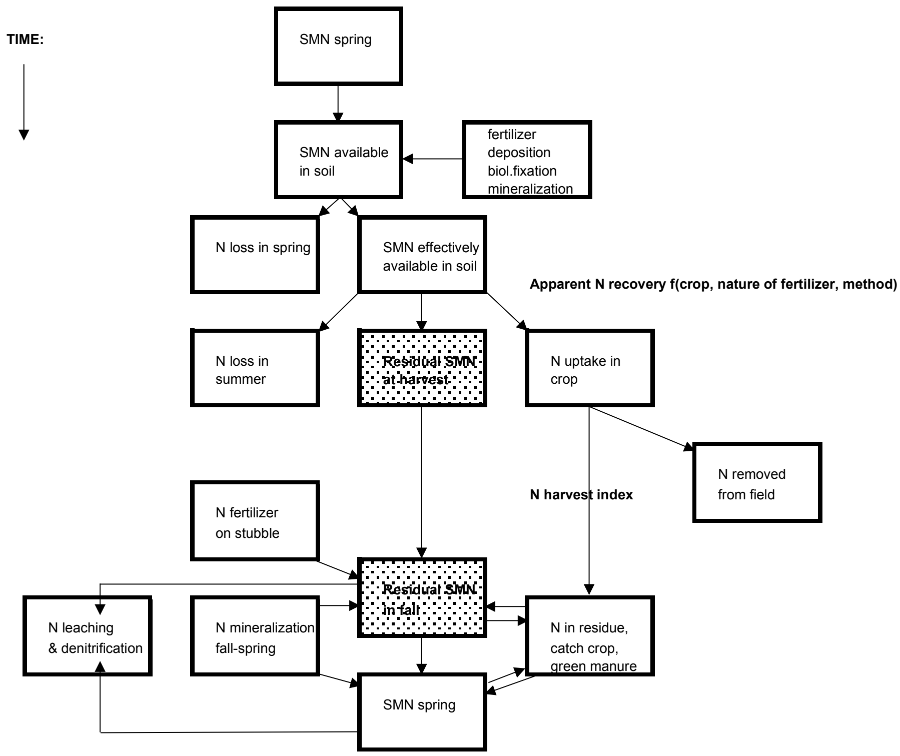


*Figure 1.2. Major processes governing the balance of mineral nitrogen in the soil profile. SMN is the amount of mineral N in the soil profile ($N_{min}$).*

# 2. Theory: balance approximations for $N_{min}$ at harvest

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The total balance equation for mineral nitrogen in the soil serves as our starting point:

$$N_{min,H} = N_{min,S} + M_{net} + D + F + A - U - U_{CR} - \Sigma L_i \qquad 2.1$$

This expression shows $N_{min,H}$ as the difference between a few positive and a few negative terms. Most of these are large in comparison with the net balance result and they are, moreover, variable and difficult to quantify under practical conditions. Of the right hand side terms in Eq. 2.1, only the N rate $A$ and sometimes $U$ and $N_{min,S}$ were measured in most of the trials that provided the experimental database for this study. The often unknown variation in the remaining balance terms causes 'noise' in regression-based models for $N_{min,H}$. Some of this noise can be removed, depending on the available information and on the – associated - choice of the regressor ($x$-variate).

A limited number of the experiments analysed for this study included treatments without fertiliser-N or manure-N inputs, referred to as 'zero-N plots'. $N_{min,H}$ observations on these plots can be used to remove part of the uncertainty 'accumulated' by the summation expressed in Eq. 2.1, by cancelling out some of the terms. For the zero-N plots, Eq. 2.1 is rewritten as:

$$N_{min,H,0} = N_{min,S,0} + M_{net,0} + D_0 + F_0 + A_0 - U_0 - U_{CR,0} - \Sigma L_{i,0} \qquad 2.2$$

with N rate $A_0$=0 and where the subscript in all variable names refers to the zero-N input. The increment in $N_{min,H}$ resulting from the application of N is found by subtracting the terms in Eq 2.2 from those in Eq 2.1 as:

$$\Delta N_{min,H} = A - (U - U_0) - (U_{CR} - U_{CR,0}) - \Sigma(L_i - L_{i,0}) \qquad 2.3$$

with

$$\Delta N_{min,H} \equiv N_{min,H} - N_{min,H,0} \qquad 2.4$$

and where it is implied that Spring mineral nitrogen $N_{min,S}$, net mineralisation $M_{net}$, deposition $D$ and biological fixation $F$ in treatments that received N-inputs are all equal to their respective values in zero-N plots. Rearranging Eqs. 2.1, 2.3 and 2.4 gives:

$$N_{min,H} = N_{min,H,0} + A - (U - U_0) - (U_{CR} - U_{CR,0}) - \Sigma(L_i - L_{i,0}) \qquad 2.5$$

[The notion that mineralisation is not affected by N application is certainly invalid for grassland, where in-season turnover of N captured in roots and stubbles is important. It is therefore that the earlier definition (see Eq 2.1) of net mineralisation excludes the decomposition of new (in-season formed) crop residues, and thus deviates somewhat from the standard definition. For Eq. 2.5 to remain consistent in view of this turnover, the term ($U_{CR}$-$U_{CR,0}$) should be regarded, in grass, as the net fixation of N in residues over the whole season. The gross fixation would be about three times as large.]

Eq. 2.5 can be simplified by the following approximation. Let $\rho$ be the apparent N recovery in harvested crop parts, defined as $\rho \equiv (U - U_0)/A$; and let $\rho_{ini}$ be its initial value, that is, the apparent N recovery which is independent of the N-rate under conditions where N supply is low to moderate, relative to crop N demand: the so-called subcritical N rates. The upper end of this domain where $\rho_{ini}$ maintains a constant value is marked, by definition, by the critical N rate, $A_{crit}$ . In this subcritical domain the fraction of the applied N *not* captured in harvested crops parts is expressed as $(1-\rho_{ini})$, and the corresponding total amount of nitrogen as $A(1-\rho_{ini})$. Two key propositions are now introduced. The first is that the term $A(1-\rho_{ini})$ represents the sum of (i) applied N absorbed in crop residues, and (ii) the amount of applied N lost from the root zone or fixed in inaccessible form (organic matter):

$$(U_{CR} - U_{CR,0}) + \Sigma_i (L_i - L_{i,0}) = (1 - \rho_{ini}) A \qquad 2.6$$

This can be understood intuitively: had this N not been allocated to these two sinks, remaining mineral N would have been absorbed, given that crop N demand is large in the subcritical N supply range. Introduction of Eq 2.6 into Eq 2.5 then gives

$$N_{min,H} = N_{min,H,0} + A - (U - U_0) - (1 - \rho_{ini}) A \qquad 2.7$$

or

$$N_{min,H} = N_{min,H,0} + \rho_{ini} A - (U - U_0) \qquad 2.8$$

The second proposition is that Eq. 2.6 is not only valid in the N supply range where crop N demand well exceeds N supply, but also in the 'near-saturation' range where a decreasing recovery $\rho$ indicates the reduced absorption capacity of the crop. So, even at higher N rates, still a fraction $(1-\rho_{ini})$ of the applied N would be allocated to the sinks according to Eq 2.6. Figure 2.1 illustrates the principle expressed in Eq. 2.8.

As argued above, this expression follows almost directly from the mineral N balance equation, and was found by subtracting the balance terms for zero-N plots from those corresponding to fertilised plots. The major advantage of Eq 2.8 over the full balance equation (Eq 2.1) is that all terms can be determined experimentally, and this has indeed been done in many past experiments, mainly in grass and maize. This enables the verification of Eq 2.8 and the underlying two propositions, and provides a basis for further refinement of the equation by regression analysis (Chapter 5).

Eq. 2.8 can be further developed by substitution of *U,* for those cases where no observations on the N-yield *U* were made. We adopt a simple quadratic relation for this purpose, from the QUADMOD model (Ten Berge *et al.,* 2000). It expresses the response *U(A)* for N rates exceeding the critical N rate, $A_{crit}$:

$$U = U_{crit} + \rho_{ini} (A - A_{crit}) - \frac{\rho_{ini} (A - A_{crit})^2}{2 (A_{max} - A_{crit})} \qquad 2.9$$

where $U_{crit}$ is the uptake at $A$=$A_{crit}$, the 'critical point' where the response d$U$/d$A$ starts to drop below its initial value $\rho_{ini}$ as expressed by the second-order term. This uptake is written as

$$U_{crit} \equiv U_0 + \rho_{ini} A_{crit} \qquad 2.10$$

where $A_{max}$ is the N rate needed to achieve maximum biomass yield and 'full N-saturation' of the crop biomass. Combining Eqs 2.8-2.10 gives:

$$N_{min,H} = N_{min,H,0} + \frac{\rho_{ini}\,(A - A_{crit})^2}{2\,(A_{max} - A_{crit})} = N_{min,H,0} + \mu\,(A - A_{crit})^2 \quad \text{for } A > A_{crit} \qquad 2.11a$$

$$N_{min,H} = N_{min,H,0} \quad \text{for } A < A_{crit} \qquad 2.11b$$

$$\text{with } \mu \equiv \frac{\rho_{ini}}{2\,(A_{max} - A_{crit})} \qquad 2.12$$

Eq. 2.11 suggests that $(A\text{-}A_{crit})^2$ is likely to be correlated with $N_{min,H}$.

Eqs. 2.8 and 2.11 are used in Chapter 3 as a basis for deriving and testing a range of regression models, based on selected terms of these balance equations. They are therefore referred to as 'partial balance' equations.

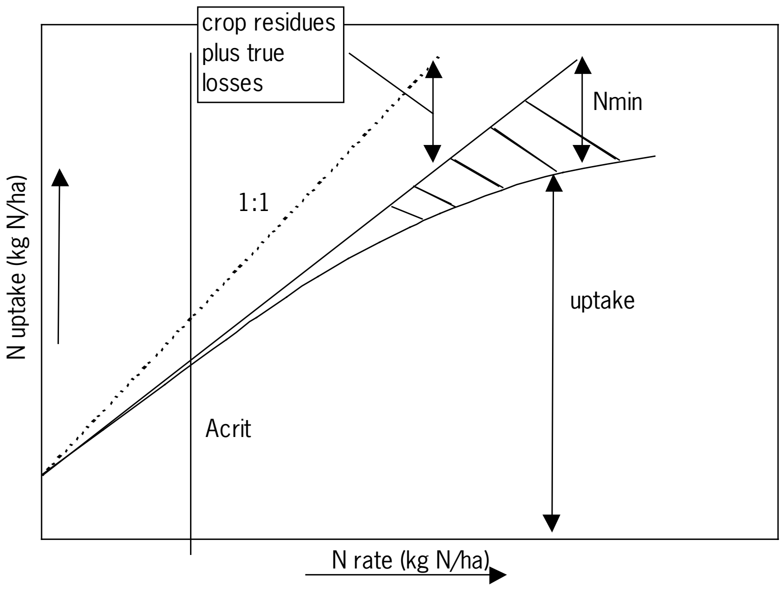


*Figure 2.1. Schematic representation of accumulation of residual mineral soil nitrogen at the time of harvest, in function of the applied N rate, as described by Eqs. 2.8 and 2.11. The base level* $N_{minH,0}$ *is here presumed to be zero.*

# 3. 'Partial balance'- regression models for $N_{min,H}$

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## 3.1 Introduction

In this chapter we take the balance equations 2.8 and 2.11 (Chapter 2) as a starting point for defining a series of regression models. These will include selected terms of the balance equations and can therefore be referred to as 'partial balance' models. Strictly speaking, this term is incorrect because the implementation in the form of regression models defeats, in a way, the balance principle: the regression coefficients that modify the balance terms have no strict physical meaning and may account for various known and unknown processes. But then, this is one of the very advantages of the regression approach: it does allow to include factors the role of which may be unknown beforehand, such as precipitation; and offers objective measures to judge the relative importance of the various factors. Regression models can be parameterized easily, and their coefficients may compensate, to some extent, for deviations that result from ignoring some of the balance terms. In short, the regression approach is attractive in problems where we have only partial understanding of the processes involved, or where only part of the relevant variables can be observed directly. Both conditions apply to the quantification of residual mineral nitrogen in soils. Nevertheless, the theory presented in Chapter 2 provides a guideline for developing and comparing regression models in the next paragraphs.

Prior to the evaluation of the various models in Paragraphs 3.5-3.7, we will introduce the data sets available for this purpose (Par. 3.2), and then first use these data to inspect a few general issues. One is to test, in Par. 3.3, the two propositions used in the derivation of Eq. 2.11 of Chapter 2. The other is to assess variation in the base level of residual mineral N, $N_{min,H,0}$ (Paragraph 3.4).

Paragraph 3.8 is devoted to applications of the QUADMOD concept to the modelling of $N_{min,H}$. Finally, Par. 3.9 deals with the modelling of $N_{min,H}$ under 'steady state' soil conditions, that is, in the case where no net changes occur of soil N pools. This may have crucial implications for the reduction of 'noise' in surplus-based models.

## 3.2 Data sources

Chapters 3, 4 and 5 compile virtually all data of experiments that were conducted during the last two decades in the Netherlands with the aim to assess the effects of fertiliser management on $N_{min,H}$. In a limited number of those trials, crop N uptake (N-yield) was observed, and often a zero-N treatment was included which yielded observations on N-yield ($U_0$) and residual mineral soil N ($N_{min,H,0}$) in absence of N-input. The trials meeting all these conditions allow a closer inspection of the principles introduced in Chapter 2, and enable a comparison of a range of regression models of increasing complexity. The datasets used for this purpose are listed in Table 3.1.

The effectiveness ('working coefficient') of N in animal manures was assumed to be equal to 0.60 (injected slurry) and 0.24 (surface applied slurry) and all N-rates were converted into effective N-rates. All N-rates refer to effective N-rates in this study.

*Table 3.1. Data sets used in this chapter to analyse relations between residual soil mineral nitrogen ($N_{min,H}$) and selected variables. All sets include observed data on crop N yield (U), N-yield in absence of N-input ($U_0$), and $N_{min,H}$ in absence of N-input ($N_{min,H,0}$). Regression models for maize and grass were based on sand data only.*

| Crops | Soil | # Trials | # Nmin observ's | Years | Source |
|---|---|---|---|---|---|
| Cauliflower | Clay | 4 | 40 | 90,92 | Everaarts, 1995 |
| Broccoli | Clay | 4 | 40 | 90-92 | Everaarts, 1995 |
| White cabbage | Clay | 4 | 42 | 92-93 | Everaarts, 1995 |
| Potatoes ware | Clay | 5 | 104 | 87-98 | Hengsdijk, 1992; Titulaer, 1997, Van Loon, 1998; Anon., 1999 |
| Potatoes starch | Sand | 6 | 113 | 91-97 | Van Loon, 1995; Wijnholds, 1995, 1996, 1997 |
| | Dal | 6 | 44 | 89-92 | Van Loon, 1995; Postma, 1995; Anon., 1999 |
| Maize silage | Clay | 7 | 84 | 85-94 | Schröder, 1990; Van der Schans, 1995; Van Dijk, 1996 |
| | Loess | 4 | 80 | 95-98 | Geelen, 1999 |
| | Sand | 97 | 423 | 75-99 | Schröder, 1985, 1987, 1989, 1990, 1992, 1993; Van Dijk, 1995, 1996, 1997, 1998; Van der Schans, 1995, 1998; Van der Schoot 2000; Anon., 1999 |
| Sugarbeet | Clay | 8 | 139 | 88-97 | Hengsdijk, 1992; Westerdijk, 1992; Van Dijk, 1999; Anon., 1999 |
| | Sand | 1 | 6 | 89 | Anon., 1999 |
| Cut grass | Sand | 27 | 373 | 80-84; 87-90; 92-94; 96-98; | Van der Meer *et al.*, 1992; Fonck (1982a,b; 1986a,b,c); Wouters *et al.*, |
| Cut grass | Peat | 5 | 39 | 92-94 | 1992; Van Bockstaele *et al.*, 1996, |
| Cut grass | Clay | 3 | 21 | 92-94 | 1997, 1998; Wadman & Sluijsmans, 1992; Anon., 2000. |

## 3.3 Validation of propositions in Chapter 2

The two key propositions introduced in Chapter 2 are validated here, as far as possible on the basis of available evidence.

The first was that the term $A(1-\rho_{ini})$ represents the sum of (i) applied N absorbed in crop residues, and (ii) the amount of applied N lost from the root zone or fixed in inaccessible form (organic matter) as expressed in Eq. 2.6. The consequence is that no mineral N would accumulate in excess of the base level, $N_{min,H,0}$, as long as applied N rates do not exceed the local value of the critical N rate, $A_{crit}$. (For a definition see Chapter 2 and Ten Berge *et al.* (2000)). This is so because the second and the third right hand side term of Eq 2.8 are equal - by definition - for subcritical N rates, and so they cancel out. The Figures 3.1 – 3.7 serve to confirm that this approximation is justified in most cases. Negative values of the x-variable in these figures correspond to subcritical doses, and the associated y-values do not differ from zero, or do so only slightly. Broccoli seems to deviate from this pattern.

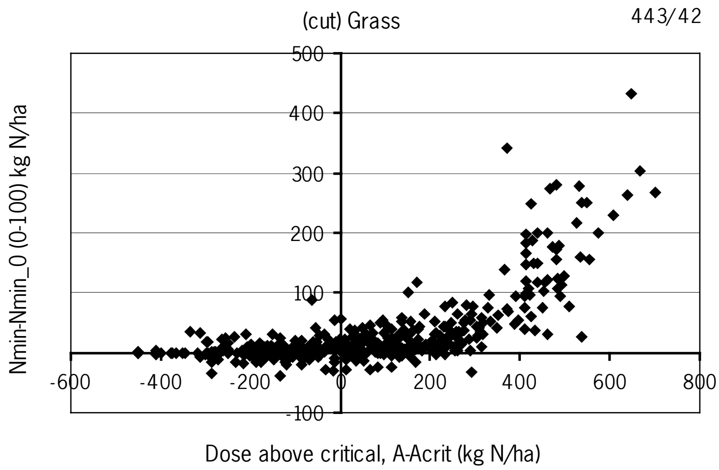



*Figure 3.1.* *Increment in residual soil N (0-100 cm) at the last cut harvest ($N_{min,H}$) in grass, relative to residual soil N observed at the same time in plots that received no N input ($N_{min,H,0}$), versus the amount by which the applied N rate exceeds the critical N rate, $A_{crit}$. The values of $N_{min,H,0}$ and $A_{crit}$ are case-specific: they vary with the location and the year of the experiment. All grass data listed in Table 3.1 are included.*

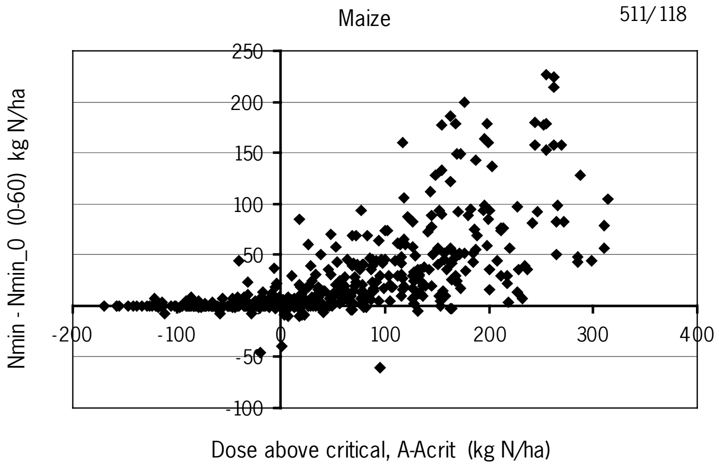



*Figure 3.2.* *Increment in residual soil N (0-60 cm) at harvest ($N_{min,H}$) in maize, relative to residual soil N observed at the same time in plots that received no N input ($N_{min,H,0}$), versus the amount by which the applied N rate exceeds the critical N rate, $A_{crit}$. The values of $N_{min,H,0}$ and $A_{crit}$ are case-specific: they vary with the location and the year of the experiment. All maize data listed in Table 3.1 are included.*

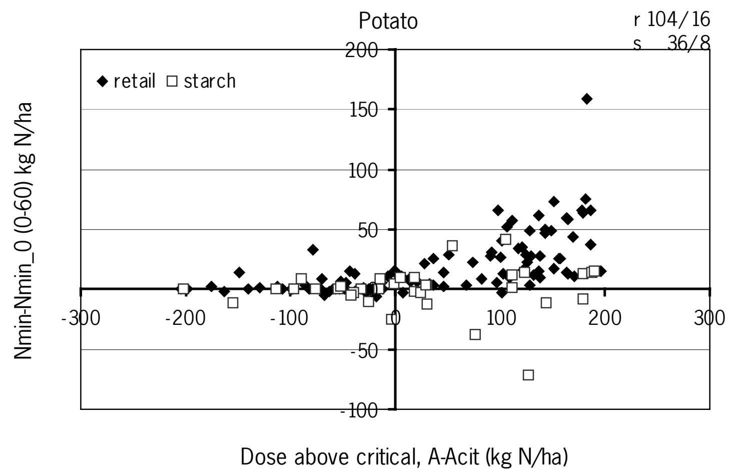



*Figure 3.3.* *Increment in residual soil N (0-60 cm) at harvest ($N_{min,H}$) in potato, relative to residual soil N observed at the same time in plots that received no N input ($N_{min,H,0}$), versus the amount by which the applied N rate exceeds the critical N rate, $A_{crit}$. The values of $N_{min,H,0}$ and $A_{crit}$ are case-specific: they vary with the location and the year of the experiment. All potato data listed in Table 3.1 are included.*

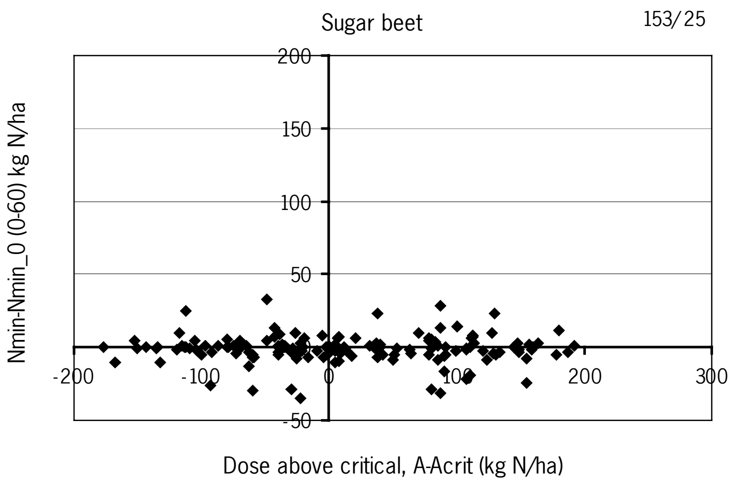



*Figure 3.4.* *Increment in residual soil N (0-60 cm) at harvest ($N_{min,H}$) in sugar beet, relative to residual soil N observed at the same time in plots that received no N input ($N_{min,H,0}$), versus the amount by which the applied N rate exceeds the critical N rate, $A_{crit}$. The values of $N_{min,H,0}$ and $A_{crit}$ are case-specific: they vary with the location and the year of the experiment. All sugar beet data listed in Table 3.1 are included.*

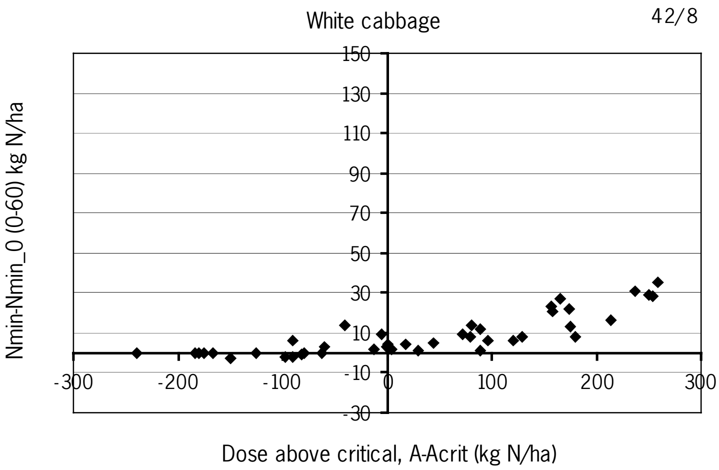



*Figure 3.5.* *Increment in residual soil N (0-60 cm) at harvest ($N_{min,H}$) in cabbage, relative to residual soil N observed at the same time in plots that received no N input ($N_{min,H,0}$), versus the amount by which the applied N rate exceeds the critical N rate, $A_{crit}$. The values of $N_{min,H,0}$ and $A_{crit}$ are case-specific: they vary with the location and the year of the experiment. All data refer to clay soils.*

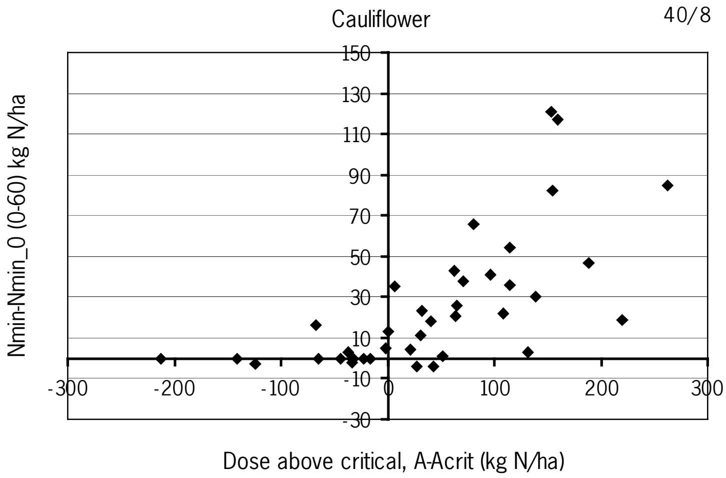



*Figure 3.6.* *Increment in residual soil N (0-60 cm) at harvest ($N_{min,H}$) in cauliflower, relative to residual soil N observed at the same time in plots that received no N input ($N_{min,H,0}$), versus the amount by which the applied N rate exceeds the critical N rate, $A_{crit}$. The values of $N_{min,H,0}$ and $A_{crit}$ are case-specific: they vary with the location and the year of the experiment. All data refer to clay soils.*

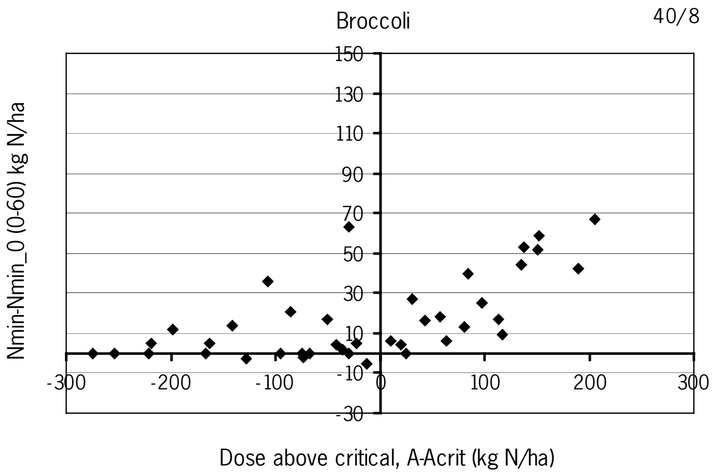



*Figure 3.7.* *Increment in residual soil N (0-60 cm) at harvest ($N_{min,H}$) in broccoli, relative to residual soil N observed at the same time in plots that received no N input ($N_{min,H,0}$), versus the amount by which the applied N rate exceeds the critical N rate, $A_{crit}$. The values of $N_{min,H,0}$ and $A_{crit}$ are case-specific: they vary with the location and the year of the experiment. All data refer to clay soils.*

The second proposition is that Eq. 2.6 is not only valid in the N supply range where crop N demand well exceeds N supply, but also in the 'near-saturation' range where a decreasing recovery $\rho$ indicates the reduced absorption capacity of the crop. One could argue against this that there is a limit to the N storage in plant parts designated as 'crop residues'. As a consequence, Eq. 2.6 would not be valid at high N rates unless the limited N sink function of crop residues would be compensated for by an increased losses term, $\Sigma(L_i\text{-}L_{i,0})$. In absence of such compensation, Eq 2.8 would be expected to underestimate $N_{\text{min,H}}$ for the higher N rates. This issue can be inspected on the basis of Figures 3.9 and 3.10, where $N_{\text{min,H}}$ calculated according to Eq. 2.8 is plotted versus observed values. No such systematic deviation appears to occur in grass. In maize, on the other hand, Eq 2.8 indeed appears to underestimate $N_{\text{min,H}}$ at higher N rates. The error introduced by the second proposition is thus likely to depend on the specific capacity of crops to absorb N in their residues.

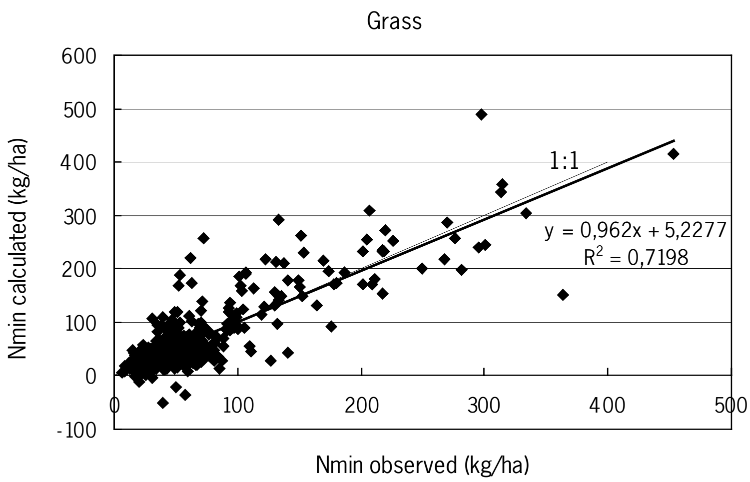



*Figure 3.8.* *Residual soil N (0-100 cm) at last cut harvest ($N_{min,H}$) in grass, calculated with the help of Eq. 2.8, versus observed values. Values of $\rho_{ini}$, $U_0$ and $N_{min,H,0}$ used in this calculation are case-specific: they vary with the location and the year of the experiment.*

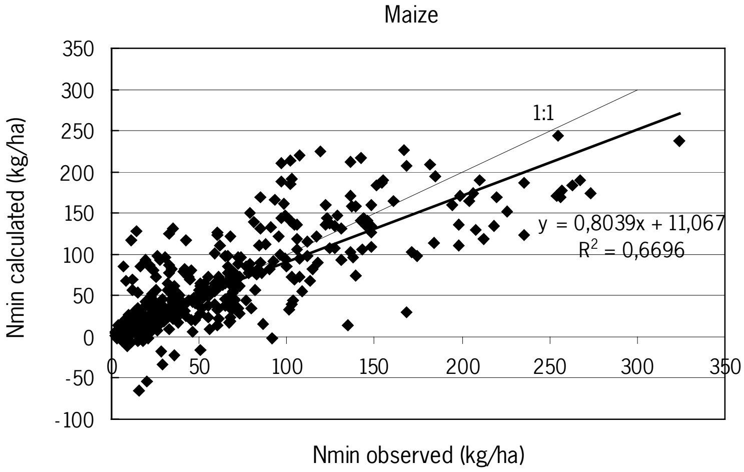



*Figure 3.9.* *Residual soil N (0-60 cm) at harvest ($N_{min,H}$) in maize, calculated with the help of Eq. 2.8, versus observed values. Values of $\rho_{ini}$ , $U_0$ and $N_{min,H,0}$ used in this calculation are case-specific: they vary with the location and the year of the experiment.*

## 3.4 The base level $N_{min,H,0}$ and the Spring value $N_{min,S}$

As shown in Eqs. 2.5 and 2.8 of Chapter 2, the base level $N_{min,H,0}$ sets the value of $N_{min,H}$ that should be expected anyhow, that is, in absence of N application. This base level may vary considerably across sites and also between years at a given site, and between crops. It is therefore, as shown later, an important factor to explain the total variance found in $N_{min,H}$.

Based on the available observations (Table 3.1), typical values of $N_{min,H,0}$ are between 15 and 80 kg N ha-1 in maize, 10 to 45 in grass, 20 to 60 in potato, and 5 to 30 kg N ha-1 in sugar beet. The trials with open field vegetables revealed values of 10-20 kg N ha-1 for white cabbage and broccoli, and 10-40 kg N ha-1 for cauliflower (all on clay soils!).

At first, one might expect that the higher $N_{min,H,0}$-values are found on soils with a relatively high seasonal mineralisation and that, therefore, a positive correlation could be expected between $N_{min,H,0}$ and the corresponding crop N-yield $U_0$ in zero-input treatments. The existence of such relation would be convenient as it would enable local corrections on observed $N_{min,H}$ in monitoring programs. Figure 3.10 shows, however, that no clear correlation is found between N-yield and $N_{min,H}$ in zero-input plots, except in maize.
At closer inspection, the absence of a correlation can be understood based on Eq. 2.11 (Chapter 2), which states that $N_{min,H}$ does not increase in response to applied N up to a certain input level, $A_{crit}$. If this is so, then why would $N_{min,H}$ respond to the amount of N liberated from the soil itself, as long as this amount is well below the level $A_{crit}$? As long as crop N demand is larger than supply, whether derived from the soil or from external inputs, no substantial amounts of $N_{min,H}$ would be expected to build up.

Now the behaviour of $N_{min,H,0}$ in maize provides a clue to understanding the variation found in $N_{min,H,0}$ in general. Maize differs from the other crops inspected here, in that a long period passes between the cessation of crop N uptake and the date of harvest, often up to two months or more. Most likely, $N_{min,H,0}$ is mainly determined by mineralisation during this period. Based on this reasoning, it can now be understood that soils with higher mineralisation potential will only show a higher build-up of $N_{min,H,0}$ if a sufficiently long period of crop 'inactivity' allows this. Such build-up will be enhanced if large doses of animal manures were applied, and this may explain that maize shows relatively high values for $N_{min,H,0}$. So, we presume that in all crops the variation found in $N_{min,H,0}$ across sites and years must be attributed, at least partly, to variations in the duration of the period between the end of crop N uptake and the moment of harvest, to variable weather conditions in this period, and to different – soil dependent - mineralisation rates during this period.

In most crops, farmers can do little in terms of crop management to change $N_{min,H,0}$ for their specific conditions in the short term, other than trying to match crop timing with the natural mineralisation pattern. In maize, however, the use of catch crops is very well possible and even seems imperative to keep $N_{min,H,0}$ within acceptable limits, on soils with high mineralisation.

Consequence of a positive correlation between $N_{min,H,0}$ and $U_0$ – as in maize - is that ignoring both these terms from the N balance represented by Eqs. 2.7 and 2.8 (Chapter 2) causes relatively large errors in estimates of $N_{min,H}$. This becomes apparent from the poor correlation in maize between the N surplus (*A-U*) and $N_{min,H}$ (Paragraph 3.5.2).

A comment should be made here with respect to the amount of mineral soil nitrogen in Spring, $N_{min,S}$. Other than most balance terms, this variable can be obtained by direct measurement at the start of the season and so it could represent, for farmers, a guide in planning N management. Regression models that account explicitly for $N_{min,S}$ would be attractive for this reason, but in most experiments in arable crops the corresponding values were not recorded. Available data for grass, however, do enable to account for $N_{min,S}$ and this aspect is treated in Chapter 4. A comparison between Eqs 2.1 and 2.5 (Chapter 2) shows that we should use either $N_{min,S}$ or $N_{min,H,0}$ in such regression models, but not both, because $N_{min,H,0}$ incorporates already the effects of $N_{min,S}$. (The latter term is equal in fertilised and non-fertilised plots.) In models expressing $N_{min,H}$ directly as function of N rate *A,* $N_{min,S}$ can be regarded as being part of *A*. In all calculations for arable crops (Chapter 5) it was presumed that $N_{min,S}$ had a fixed value, and this value was subtracted from the crop-specific recommended N rate for which the expected $N_{min,H}$ value is calculated.

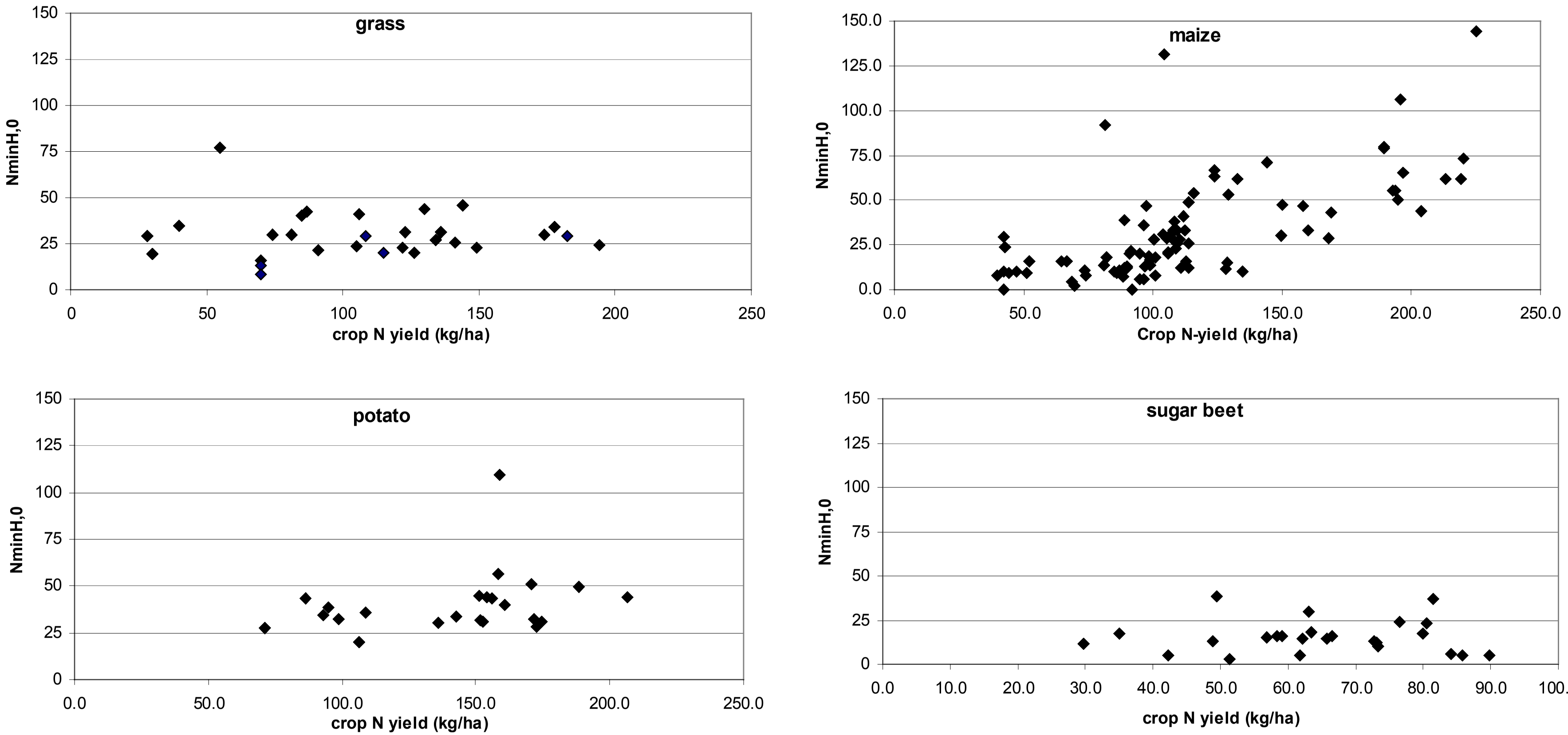



*Figure 3.10.* *Residual mineral soil N at harvest versus crop N yield, observed in treatments with zero N input, in cut grass, maize, potato and sugar beet.*

# 3.5 Linear regression models for $N_{min,H}$

## 3.5.1 The models

The structure of available data differs between crop species, and crops themselves differ, too, with respect to their $N_{min,H}$ responses. This makes a 'broad' survey of possible regression models desirable. We use Eqs. 2.8 and 2.11 as a starting point to identify suitable regressors (*x*-variates) composed of one or more balance terms, and we will inspect the performance of these 'partial balance regression models'. These models are all linear in the regression coefficients.

| | | |
|---|---|---|
| Model 1a. | $N_{min,H} = c + b^* A + e^*P$ | 3.1 |
| Model 2a. | $N_{min,H} = c + b^*(A\text{-}U) + e^* P$ | 3.2 |
| Model 3a. | $N_{min,H} = c + b^*(A\text{-}(U\text{-}U_0)) + e^* P$ | 3.3 |
| Model 4a. | $N_{min,H} = c + b^*\mu\ (A\text{-}A_{crit})^2 + e^* P$ | 3.4 |
| Model 5a. | $N_{min,H} = c + b^*(\rho_{ini}A - (U\text{-}U_0)) + e^* P$ | 3.5 |
| Model 1b. | $N_{min,H} = a^*N_{min,H,0} + b^* A + e^* P$ | 3.6 |
| Model 2b. | $N_{min,H} = a^*N_{min,H,0} + b^*(A\text{-}U) + e^* P$ | 3.7 |
| Model 3b. | $N_{min,H} = a^*N_{min,H,0} + b^*(A\text{-}(U\text{-}U_0)) + e^* P$ | 3.8 |
| Model 4b. | $N_{min,H} = a^*N_{min,H,0} + b^*\mu\ (A\text{-}A_{crit})^2 + e^* P$ | 3.9 |
| Model 5b. | $N_{min,H} = a^*N_{min,H,0} + b^*(\rho_{ini}A - (U\text{-}U_0)) + e^* P$ | 3.10 |

where *a, b, c*, and *e* are the regression coefficients; *A* is the applied N rate (fertiliser N plus effective N in animal manures), $A_{crit}$ is the critical N rate, *U* is the N yield (N uptake in harvested crop parts), and $U_0$ is the N yield observed in absence of N application, that is, harvested N that was supplied by the soil. All these variables are expressed in kg $ha^{-1}$. $\mu$ is a crop specific coefficient (see Eq. 2.11 Chapter 2; and Paragraph 3.8) that can be expressed in QUADMOD parameters. The values for $\mu$ were fixed *a priori*, based on independent ('generic') values of the QUADMOD crop parameters. ($\mu$ =0.000924 ha $kg^{-1}$ for grass and 0.00175 ha $kg^{-1}$ for maize.)
*P* is the precipitation (mm) accumulated over the entire growing season. For the maize data sets, this variable was assessed as the integral of precipitation between the actual sowing date and actual harvest date corresponding to the particular experiment. For grass, precipitation was integrated over the period from April 1st to October 15th for all data sets. Daily precipitation data from the nearest KNMI weather station were used, both for the grass and the maize experiments. The mean value of *P* was 450 mm for the grass experiments and 345 mm for the maize experiments.

## 3.5.2 Results for grass and maize

Our analysis focusses (cut) grass and maize, because these are dominant crops and the data sets available for these crops are far more numerous than for other crops, especially with reference to sandy soils. For the purpose of regression analysis, we used for these two crops only data from sandy soils. The results for (ware) potato, sugar beet, cauliflower, broccoli and white cabbage are given in a separate paragraph (3.5.4). Virtually all data on those crops refer to clay soils, and the results are not always consistent with the findings for grass and maize on sand.

The results obtained with the 10 linear models are given in Tables 3.2 (grass) and 3.3 (maize).

In grass, a gradual improvement of the correlation coefficient with increasing complexity of the model is seen, with the percentage of variance accounted for ($R^2_{adjusted}$, here also referred to as $R^2$) increasing from about 53% to about 76%. The inclusion of $N_{min,H,0}$ in the model does not bring an improvement. Comparison between the model series 1a-5a *versus* 1b-5b shows, however, that the importance of the precipitation term *eP* diminishes when $N_{min,H,0}$ is introduced into the model, suggesting that the negative

effect of rainfall on $N_{min,H}$ can be largely expressed via the associated variation in $N_{min,H,0}$. In the 1b-5b series, the effect of rainfall becomes very small and even positive values appear for *e*.
For grass, Models 4 and 5 show the best performance, both with and without the $N_{min,H,0}$ term, in terms of $R^2$. These models show values for coefficients *a* and *b* that are reasonably close to unity, suggesting that indeed the associated – more complex -regressors are a better approximation of the overall mineral N balance than those in Models 1-3.

The relation between model complexity and $R^2$ is less consistent in maize (Table 3.3). Although we do see better fits with the Models 3a-5a than with Models 1a-2a, this ranking vanishes upon including $N_{min,H,0}$ in the model. The general pattern with maize is that adopting $N_{min,H,0}$ into the model results in a drastic improvement of the fit. Then, all models perform roughly equally well, and the simplest expression with N rate $A$ as regressor behaves surprisingly well, with 73% of the variance explained. (In grass this was only 53%.) We see again – as in grass – that the importance of the $eP$ term decreases as we move from the 1a-5a to the 1b-5b model series.
Model 2, with $A$-$U$ as regressor, performs least of all, both with and without the $N_{min,H,0}$ term, but the fit is really poor if this term is omitted. An explanation for this lack of correlation, specifically in maize, has been suggested in Paragraph 3.4.
In favor of the Models 4 and 5 is – as in grass – that the coefficients *a* and *b* approximate here, better than for other models, the value of 1.

*Table 3.2. Percentage of variance accounted for, and estimated regression parameters for Models 1a-5a ($N_{min,H,0}$ not included as regressor) and Models 1b-5b (which include $N_{min,H,0}$) for grass on sandy soils.*

| Grass<br>Model | estimate<br>*c* | se | estimate<br>*b* | se | estimate<br>*e* | se | $R^2_{adjusted}$ |
|---|---|---|---|---|---|---|---|
| 1a. $A$ | 64.3 | 19.0 | 0.238 | 0.015 | -0.151 | 0.042 | 53.2% |
| 2a. $A-U$ | 204.0 | 17.0 | 0.604 | 0.034 | -0.219 | 0.039 | 59.0% |
| 3a. $A-(U-U_0)$ | 95.3 | 15.5 | 0.660 | 0.031 | -0.167 | 0.035 | 67.0% |
| 4a. $\mu\,(A-A_{crit})^2$ | 80.4 | 13.0 | 0.720 | 0.026 | -0.110 | 0.029 | 77.2% |
| 5a. $\rho_{ini}A-(U-U_0)$ | 44.3 | 13.7 | 0.806 | 0.030 | -0.019 | 0.031 | 75.8% |
| | estimate<br>*a* | se | estimate<br>*b* | se | estimate<br>*e* | se | $R^2_{adjusted}$ |
| 1b. $A$ | 0.97 | 0.30 | 0.240 | 0.015 | -0.070 | 0.021 | 53.0% |
| 2b. $A-U$ | 3.46 | 0.27 | 0.638 | 0.033 | 0.024 | 0.018 | 61.6% |
| 3b. $A-(U-U_0)$ | 1.68 | 0.24 | 0.670 | 0.030 | -0.062 | 0.017 | 68.3% |
| 4b. $\mu\,(A-A_{crit})^2$ | 0.95 | 0.21 | 0.726 | 0.027 | 0.009 | 0.015 | 75.5% |
| 5b. $\rho_{ini}A-(U-U_0)$ | 0.83 | 0.21 | 0.806 | 0.030 | 0.027 | 0.014 | 76.3% |

*Table 3.3. Percentage of variance accounted for, and estimated regression parameters for Models 1a-5a ($N_{min,H,0}$ not included as regressor) and Models 1b-5b (which include $N_{min,H,0}$) for maize on sandy soils.*

| Maize Model | estimate $c$ | se | estimate $b$ | se | estimate $e$ | se | $R^2_{adjusted}$ |
|---|---|---|---|---|---|---|---|
| 1a. $A$ | 55.0 | 0.5 | 0.447 | 0.032 | -0.099 | 0.028 | 36.2% |
| 2a. $A$-$U$ | 120.0 | 11.0 | 0.353 | 0.045 | -0.099 | 0.032 | 15.5% |
| 3a. $A$-($U$-$U_0$) | 60.7 | 8.1 | 0.681 | 0.036 | -0.108 | 0.024 | 51.9% |
| 4a. $\mu\,(A\text{-}A_{crit})^2$ | 80.7 | 8.3 | 1.153 | 0.066 | -0.128 | 0.025 | 47.6% |
| 5a. $\rho_{ini}A$–($U$-$U_0$) | 70.1 | 8.0 | 1.008 | 0.052 | -0.112 | 0.024 | 52.7% |
| | estimate $a$ | se | estimate $b$ | se | estimate $e$ | se | $R^2_{adjusted}$ |
| 1b. $A$ | 1.44 | 0.06 | 0.388 | 0.021 | -0.074 | 0.009 | 73.3% |
| 2b. $A$-$U$ | 1.91 | 0.07 | 0.360 | 0.028 | 0.046 | 0.010 | 63.3% |
| 3b. $A$-($U$-$U_0$) | 1.25 | 0.06 | 0.531 | 0.028 | -0.037 | 0.008 | 74.0% |
| 4b. $\mu\,(A\text{-}A_{crit})^2$ | 1.35 | 0.07 | 0.861 | 0.052 | -0.022 | 0.009 | 69.9% |
| 5b. $\rho_{ini}A$–($U$-$U_0$) | 1.24 | 0.07 | 0.745 | 0.044 | -0.013 | 0.009 | 70.5% |

### 3.5.3 Patterns of $N_{min,H}$ versus selected regressors

This paragraph illustrates graphically, for the example case of maize, the patterns of $N_{min,H}$ versus the various regressors, each of which represents one or more components of the mineral N balance. (See also Chapter 2.). All figures are based on the same data sets, as analysed in the previous paragraph.

As a general rule we should expect the relation between $N_{min,H}$ and the applied N rate A to be non-linear in $A$, because the uptake $U$ tends to level off at high N supply and so more N will remain 'unused', per unit applied N, as the crop approaches a state of 'nitrogen-saturation'. Chapter 5 will address a large range crops for which $N_{min,H}$ is described by a regression model that is non-linear in both $A$ and in the parameters, and will confirm this expectation. In Figure 3.11, however, the non-linearity in $A$ is not so evident - as also supported by the good performance of Model 1. This is partly the result of merging data from different experiments.

Models expressing $N_{min,H}$ as just a function of the applied N rate are attractive because they require no additional information. Large residuals, on the other hand, are found due to variation in $U$, $U_0$ and $N_{min,H,0}$ that exist across experiments (i.e., locations, years), as explained in Chapter 2.

Figure 3.12 underlines the poor performance of the surplus-based Model 2a in the previous paragraph. With the help of Eq. 2.5 (Chapter 2) it can be understood why the N-surplus ($A$-$U$) should be a rather poor indicator for $N_{min,H}$, given the balance terms ignored when taking just ($A$-$U$) as regressor. The large variation normally found in $U_0$ – with values between 50 and 200 kg N ha$^{-1}$ - causes a high level of 'noise' in Figure 3.12, and it is common in all crops to find negative surplusses associated with considerable $N_{min,H}$ values. In maize, 'noise' in the $N_{min,H}$ versus ($A$-$U$) relation is especially large because $U_0$ is large relative to $A$, to $U$, and to their difference, but also because $N_{min,H,0}$ and $U_0$ are positively correlated as was demonstrated in Fig. 3.10, which enhances the error caused by ignoring these terms (See Eq. 2.5). Further, variation in the effectiveness ('working coefficient') of animal manures should be mentioned here as another possible cause of 'noise': we used a fixed value for this coefficient in converting all N-inputs to effective-N doses. As N was often applied in the form of animal manures, in the maize trials, this variation is more expressed in maize than in other crops.

Moreover, late-season mineralisation from manures (beyond 'uptake season') may have contributed to large and variable $N_{min,H}$ in maize.

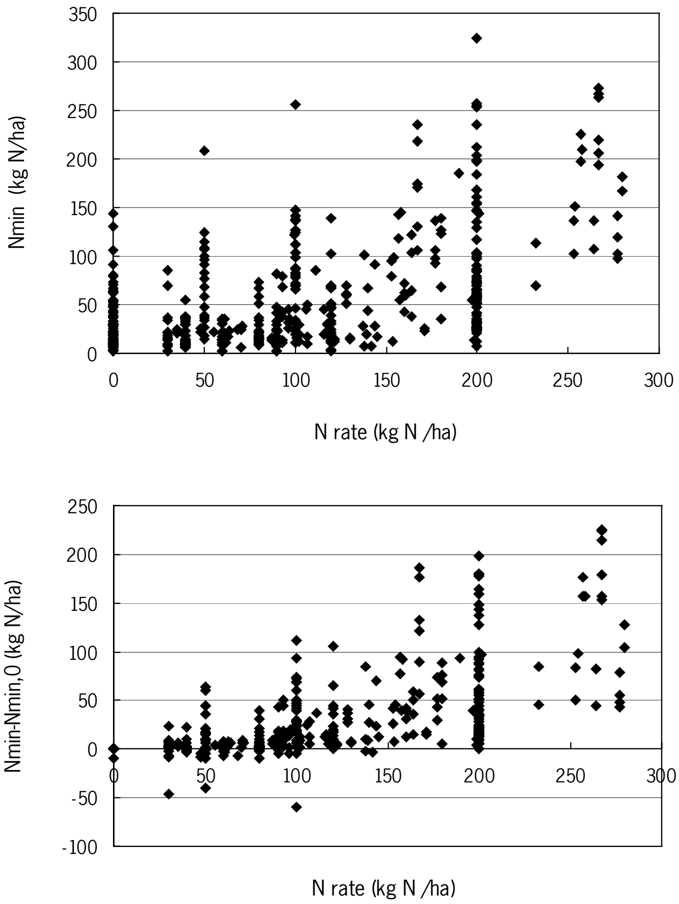



*Figure 3.11.* *Residual mineral N at harvest ($N_{min,H}$) observed in the 0-60 cm soil layer, versus the rate of effective N applied, in maize on sandy soils in the Netherlands (top). The lower graph shows the difference ($N_{min,H}$.-$N_{min,H,0}$) between treatments that received N input and those that received no N input, versus the rate of effective N applied.*

**Note on the definition of N-surplus**

It is stressed that N surplus is defined in this chapter as the difference between effective N input (only) and crop offtake. This deviates from the standard definition where the total N input is used in calculating the surplus. We chose the 'narrower' definition because more 'noise' would be introduced in the various relations if total N input were used in calculating the surplus. The long term effects of N that is 'ineffective' for crop nutrition in the short term are discussed in the last paragraph of this chapter.

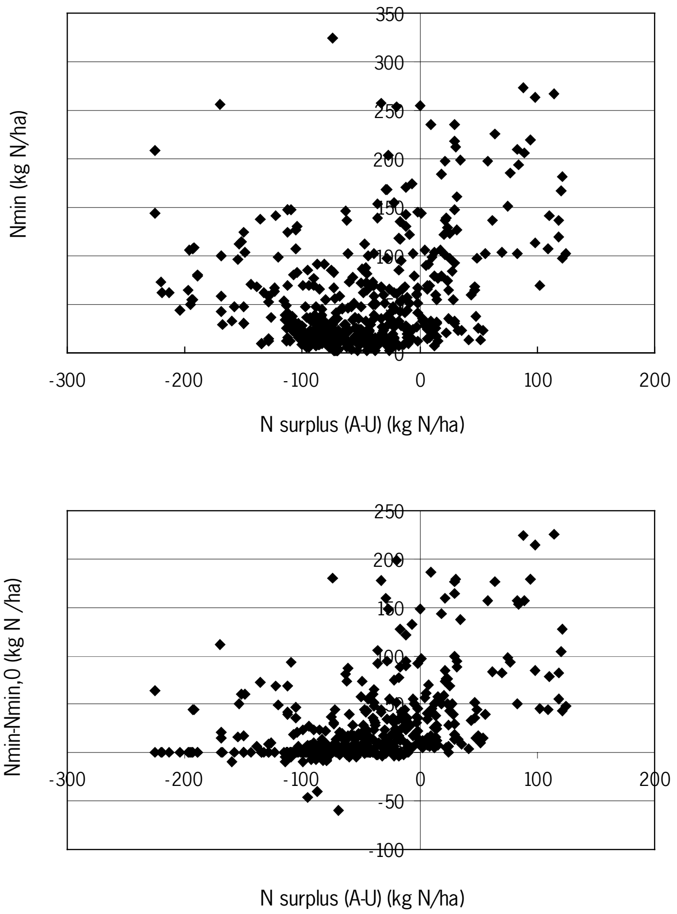



*Figure 3.12. Residual mineral N at harvest ($N_{min,H}$) observed in the 0-60 cm soil layer, versus the N surplus, in maize on sandy soils in the Netherlands (top). The lower graph shows the difference ($N_{min,H}$.- $N_{min,H,0}$) between treatments that received N input and those that received no N input, versus the N surplus. In both cases, the N surplus is the rate of effective N applied minus N offtake by the crop.*

If we use $A$-($U$-$U_0$) as regressor, the surplus is corrected for local soil fertility $U_0$ and this improves the relation with $N_{min,H}$ considerably (Figure 3.13). Obviously there is no problem with negative surplusses here: the corrected surplus is the amount of N that remains from the effective input $A$ after subtracting the N recovered from this input by the crop. The figure shows that high $N_{min,H}$ at $A$-($U$-$U_0$)=0 seen in the top graph are entirely due to high base values $N_{min,H,0}$; as they disappear in the bottom graph in Figure 3.13.

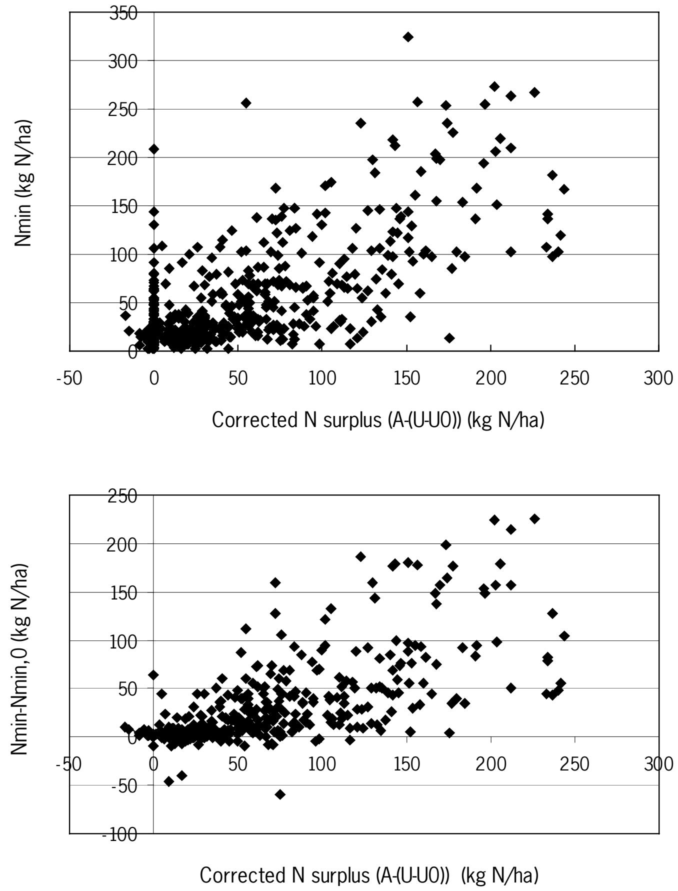
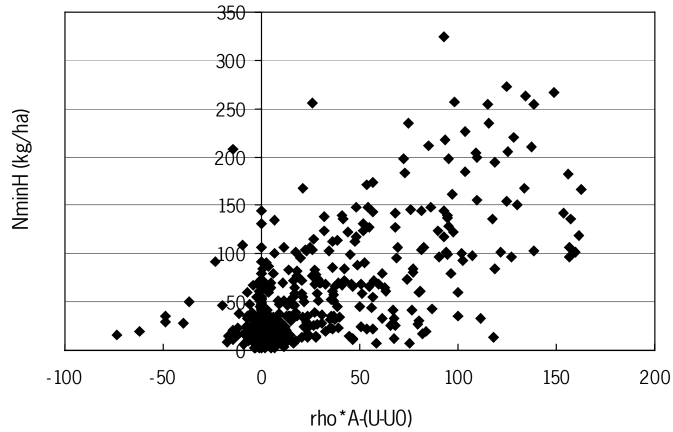



*Figure 3.13. Residual mineral N at harvest ($N_{min,H}$) observed in the 0-60 cm soil layer, versus the $U_0$-corrected N surplus, or 'surplus from fertiliser', in maize on sandy soils in the Netherlands (top). The lower graph shows the difference ($N_{min,H}$.- $N_{min,H,0}$) between treatments that received N input and those that received no N input, versus the corrected N surplus.*



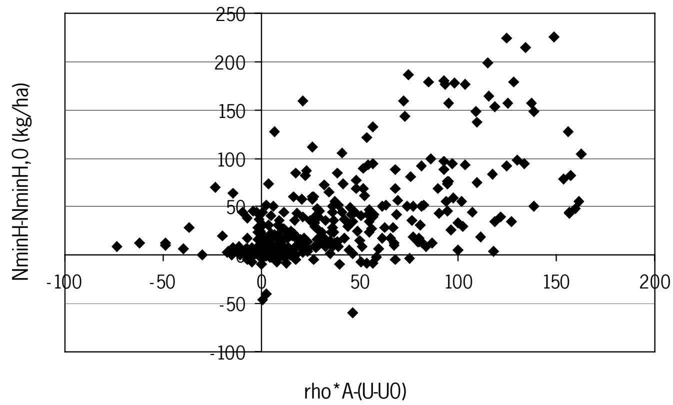
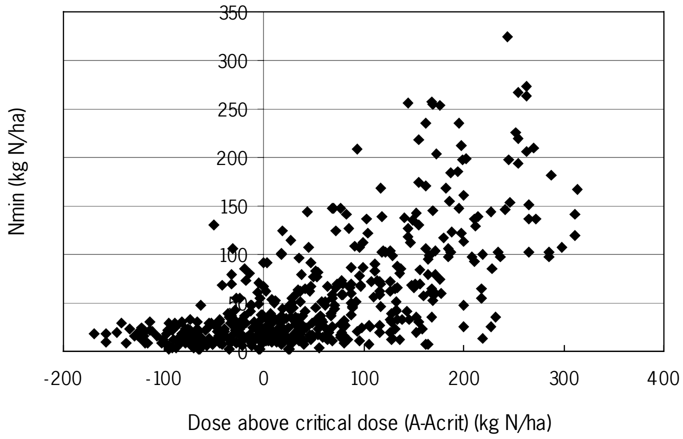




*Figure 3.14. Residual mineral N at harvest ($N_{min,H}$) observed in the 0-60 cm soil layer, versus $\rho_{ini}A$-(U-$U_0$), in maize on sandy soils in the Netherlands (top). The lower graph shows the difference ($N_{min,H}$.- $N_{min,H,0}$) between treatments that received N input and those that received no N input, versus the same x-variate.*

Introducing $\rho_{ini}A$-(U-$U_0$) as x-variate does not improve the correlation with $N_{min,H}$ (cf. Table 3.3). As discussed earlier, the proposition that a fraction (1-$\rho_{ini}$) of the applied N rate is entirely lost (and thus not found as residual mineral N) apparently does not hold strictly in maize, as it does in grass. Nevertheless, the change in the coefficient b from 0.68 (Model 3a) to 1.0 (Model 5a) suggests that the structure of a model based on $\rho_{ini}A$-(U-$U_0$) may be more attractive than one based on *A-(U-*$U_0$) only.

Finally, Figure 3.15 demonstrates the pattern of the relation with $N_{min,H}$ when the regressor $\rho_{ini}A$-(U-$U_0$) is approximated by ($A$-$A_{crit}$)$^2$ (see Chapter 2). Though the figure suggests a coalescence of the data points, relative to Figure 3.14, the correlation coefficient hardly changes (Table 3.3).



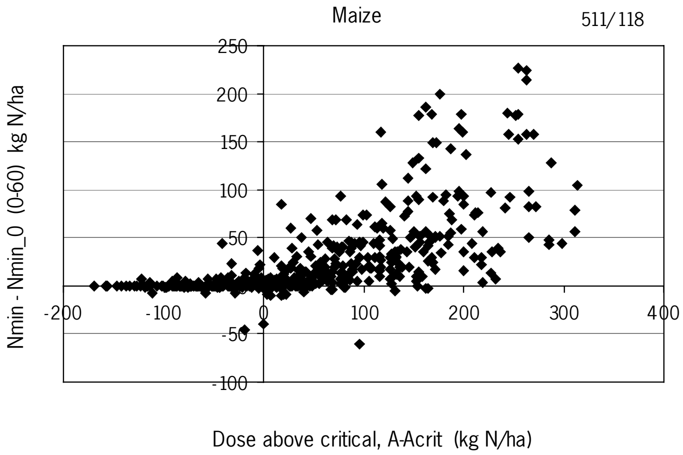




*Figure 3.15. Residual mineral N at harvest ($N_{min,H}$) observed in the 0-60 cm soil layer, versus $(A-A_{crit})^2$, in maize on sandy soils in the Netherlands (top). The lower graph shows the difference ($N_{min,H}$- $N_{min,H,0}$) between treatments that received N input and those that received no N input, versus the same x-variate.*

### 3.5.4 Crops other than grass and maize

The results obtained with the linear regression models of Paragraph 3.5.1 in potato, sugar beet, white cabbage, cauliflower, and broccoli are given in Tables 3.4 to 3.8. Note that virtually all data refer to clay soils (cf Table 3.1).
In analysing the potato data, we omitted all data on starch potato because $N_{\mathrm{min,H}}$ values were very scattered and seemed inconsistent with N management. (The data were shown in Figure 3.3.)

The general pattern with these five crops, as with grass and maize, is that models improve consistently by including the term $N_{\mathrm{min,H,0}}$ as a regressor, as can be seen by comparing the series 1a-5a with 1b-5b within each of the tables. The only exception is broccoli.

No single model comes out as an overall best model. In potato, Model 4 performs best but Model 5, which has very similar structure (cf Chapter 2), gives very poor results. The straight dose, $A$, shows a reasonable correlation with $N_{\mathrm{min,H}}$ for this crop, compared with the other models. Irrespective of the model, no better values for $R^2$ than about 60% were obtained in potato.

In sugar beet, correlations are very poor but then all $N_{\mathrm{min,H}}$ observations remained low and could hardly be distinguished from the base values (See also Figure 3.4).

The three vegetable crops show variable results. In white cabbage, Model 4b is the best and Model 5 the least, in terms of $R^2$. In cauliflower, Models 3 and 5 are the best, and 4 is the worst, both with and without inclusion of $N_{\mathrm{min,H,0}}$. In broccoli, all models except Model 5 perform approximately equal, both with and without inclusion of $N_{\mathrm{min,H,0}}$. In broccoli no more than about 60% of the variance could be explained. This fraction was higher in cauliflower (up to 76%, with model 5) and white cabbage (up to 86%, with Model 4).

Of all crops tested, only cauliflower and broccoli show values for the coefficient *b* that are well above 1.0 in Models 4 and 5. This suggests that at higher N doses, more N is left as residual mineral soil N than expected on the basis of Eqs. 2.8 and 2.11, and that the second proposition tested in Paragraph 3.3 is invalid for these crops.

*Table 3.4. Percentage of variance accounted for, and estimated regression parameters for Models 1a-5a ($N_{min,H,0}$ not included as regressor) and Models 1b-5b (which include $N_{min,H,0}$) for ware potato on clay soils.*

| Ware potato Model | estimate *c* | se | estimate *b* | se | estimate *e* | se | $R^2_{\mathrm{adjusted}}$ |
|---|---|---|---|---|---|---|---|
| 1a. $A$ | 66.0 | 6.6 | 0.16 | 0.02 | -0.08 | 0.02 | 45.6% |
| 2a. $A$-$U$ | 86.9 | 6.5 | 0.15 | 0.03 | -0.07 | 0.02 | 33.5% |
| 3a. $A$-($U$-$U_0$) | 67.6 | 6.8 | 0.20 | 0.03 | -0.08 | 0.02 | 41.9% |
| 4a. $\mu$ ($A$-$A_{\mathrm{crit}}$)$^2$ | 72.3 | 5.5 | 0.69 | 0.07 | -0.09 | 0.01 | 56.3% |
| 5a. $\rho_{\mathrm{ini}}A$–($U$-$U_0$) | 85.2 | 7.5 | 0.13 | 0.09 | -0.09 | 0.02 | 18.6% |
| | estimate *a* | se | estimate *b* | se | estimate *e* | se | $R^2_{\mathrm{adjusted}}$ |
| 1b. $A$ | 1.34 | 0.11 | 0.17 | 0.02 | -0.04 | 0.01 | 58.8% |
| 2b. $A$-$U$ | 1.82 | 0.10 | 0.22 | 0.02 | 0.00 | 0.01 | 55.1% |
| 3b. $A$-($U$-$U_0$) | 1.37 | 0.11 | 0.23 | 0.03 | -0.04 | 0.01 | 55.7% |
| 4b. $\mu$ ($A$-$A_{\mathrm{crit}}$)$^2$ | 1.42 | 0.10 | 0.71 | 0.07 | -0.03 | 0.01 | 61.1% |
| 5b. $\rho_{\mathrm{ini}}A$–($U$-$U_0$) | 1.64 | 0.13 | 0.25 | 0.08 | -0.03 | 0.01 | 26.8% |

*Table 3.5. Percentage of variance accounted for, and estimated regression parameters for Models 1a-5a ($N_{min,H,0}$ not included as regressor) and Models 1b-5b (which include $N_{min,H,0}$) for sugar beet on clay soils.*

| Sugar beet Model | estimate *c* | se | estimate *b* | se | estimate *e* | se | $R^2_{adjusted}$ |
|---|---|---|---|---|---|---|---|
| 1a. *A* | 3.31 | 4.95 | 0.01 | 0.01 | 0.02 | 0.01 | 2.6% |
| 2a. *A-U* | 6.33 | 4.92 | 0.02 | 0.01 | 0.02 | 0.01 | 4.5% |
| 3a. $A-(U-U_0)$ | 3.19 | 4.85 | 0.02 | 0.01 | 0.02 | 0.01 | 4.3% |
| 4a. $\mu\,(A-A_{crit})^2$ | 4.27 | 4.96 | 0.003 | 0.10 | 0.02 | 0.01 | 1.8% |
| 5a. $\rho_{ini}A-(U-U_0)$ | 3.07 | 4.86 | 0.04 | 0.02 | 0.02 | 0.01 | 4.4% |
| | estimate *a* | se | estimate *b* | se | estimate *e* | se | $R^2_{adjusted}$ |
| 1b. *A* | 0.34 | 0.08 | 0.01 | 0.01 | 0.02 | 0.003 | 14.0% |
| 2b. *A-U* | 0.34 | 0.08 | 0.02 | 0.01 | 0.02 | 0.002 | 15.3% |
| 3b. $A-(U-U_0)$ | 0.33 | 0.08 | 0.02 | 0.01 | 0.02 | 0.003 | 14.9% |
| 4b. $\mu\,(A-A_{crit})^2$ | 0.35 | 0.09 | 0.01 | 0.09 | 0.02 | 0.003 | 13.3% |
| 5b. $\rho_{ini}A-(U-U_0)$ | 0.34 | 0.08 | 0.04 | 0.02 | 0.02 | 0.003 | 15.6% |

*Table 3.6. Percentage of variance accounted for, and estimated regression parameters for Models 1a-5a ($N_{min,H,0}$ not included as regressor) and Models 1b-5b (which include $N_{min,H,0}$) for white cabbage on clay soils.*

| White cabbage Model | estimate *c* | se | estimate *b* | se | estimate *e* | se | $R^2_{adjusted}$ |
|---|---|---|---|---|---|---|---|
| 1a. *A* | 2.48 | 7.76 | 0.06 | 0.01 | 0.02 | 0.01 | 40.6% |
| 2a. *A-U* | 6.85 | 7.44 | 0.09 | 0.02 | 0.02 | 0.01 | 43.1% |
| 3a. $A-(U-U_0)$ | 2.31 | 7.48 | 0.10 | 0.02 | 0.02 | 0.01 | 44.7% |
| 4a. $\mu(A-A_{crit})^2$ | 16.9 | 6.8 | 0.43 | 0.07 | 0.00 | 0.01 | 52.0% |
| 5a. $\rho_{ini}A-(U-U_0)$ | 9.84 | 7.46 | 0.34 | 0.06 | 0.01 | 0.01 | 42.0% |
| | estimate *a* | se | estimate *b* | se | estimate *e* | se | $R^2_{adjusted}$ |
| 1b. *A* | 1.04 | 0.17 | 0.05 | 0.01 | -0.002 | 0.005 | 70.3% |
| 2b. *A-U* | 1.05 | 0.16 | 0.08 | 0.01 | 0.010 | 0.005 | 73.0% |
| 3b. $A-(U-U_0)$ | 0.99 | 0.16 | 0.08 | 0.01 | 0.00 | 0.01 | 71.4% |
| 4b. $\mu\,(A-A_{crit})^2$ | 1.20 | 0.11 | 0.41 | 0.04 | 0.00 | 0.00 | 86.1% |
| 5b. $\rho_{ini}A-(U-U_0)$ | 0.98 | 0.18 | 0.28 | 0.05 | 0.01 | 0.01 | 65.2% |

*Table 3.7. Percentage of variance accounted for, and estimated regression parameters for Models 1a-5a ($N_{min,H,0}$ not included as regressor) and Models 1b-5b (which include $N_{min,H,0}$) for cauliflower on clay soils.*

| Cauliflower Model | estimate *c* | se | estimate *b* | se | estimate *e* | se | $R^2_{adjusted}$ |
|---|---|---|---|---|---|---|---|
| 1a. $A$ | 194 | 28 | 0.23 | 0.04 | -0.87 | 0.15 | 55.0% |
| 2a. $A$-$U$ | 217 | 29 | 0.27 | 0.05 | -0.87 | 0.15 | 54.6% |
| 3a. $A$-($U$-$U_0$) | 189 | 25 | 0.31 | 0.04 | -0.86 | 0.13 | 64.7% |
| 4a. $\mu$ $(A-A_{crit})^2$ | 184 | 31 | 1.41 | 0.34 | -0.74 | 0.16 | 44.3% |
| 5a. $\rho_{ini}A$–($U$-$U_0$) | 161 | 20 | 1.20 | 0.13 | -0.68 | 0.10 | 75.8% |
| | estimate *a* | se | estimate *b* | se | estimate *e* | se | $R^2_{adjusted}$ |
| 1b. $A$ | 2.12 | 0.22 | 0.23 | 0.03 | -0.15 | 0.04 | 70.0% |
| 2b. $A$-$U$ | 2.36 | 0.22 | 0.27 | 0.04 | -0.07 | 0.03 | 72.1% |
| 3b. $A$-($U$-$U_0$) | 1.98 | 0.21 | 0.28 | 0.04 | -0.14 | 0.04 | 74.0% |
| 4b. $\mu$ $(A-A_{crit})^2$ | 2.04 | 0.26 | 1.37 | 0.29 | -0.06 | 0.04 | 59.8% |
| 5b. $\rho_{ini}A$–($U$-$U_0$) | 1.57 | 0.21 | 1.01 | 0.14 | -0.05 | 0.03 | 73.6% |

*Table 3.8. Percentage of variance accounted for, and estimated regression parameters for Models 1a-5a ($N_{min,H,0}$ not included as regressor) and Models 1b-5b (which include $N_{min,H,0}$) for broccoli on clay soils.*

| Broccoli Model | estimate *c* | se | estimate *b* | se | estimate *e* | se | $R^2_{adjusted}$ |
|---|---|---|---|---|---|---|---|
| 1a. $A$ | 1.64 | 5.29 | 0.15 | 0.02 | 0.06 | 0.03 | 54.7% |
| 2a. $A$-$U$ | 7.58 | 4.69 | 0.17 | 0.02 | 0.05 | 0.03 | 58.0% |
| 3a. $A$-($U$-$U_0$) | 2.11 | 5.08 | 0.17 | 0.02 | 0.06 | 0.03 | 57.2% |
| 4a. $\mu$ $(A-A_{crit})^2$ | 19.1 | 4.5 | 1.61 | 0.24 | 0.01 | 0.04 | 55.0% |
| 5a. $\rho_{ini}A$–($U$-$U_0$) | 25.0 | 4.9 | 1.68 | 0.29 | -0.04 | 0.04 | 48.2% |
| | estimate *a* | se | estimate *b* | se | estimate *e* | se | $R^2_{adjusted}$ |
| 1b. $A$ | 0.61 | 0.87 | 0.15 | 0.02 | 0.02 | 0.07 | 55.2% |
| 2b. $A$-$U$ | 1.44 | 0.79 | 0.17 | 0.02 | -0.03 | 0.07 | 58.8% |
| 3b. $A$-($U$-$U_0$) | 0.70 | 0.84 | 0.17 | 0.02 | 0.01 | 0.07 | 57.8% |
| 4b. $\mu$ $(A-A_{crit})^2$ | 3.36 | 0.77 | 1.63 | 0.24 | -0.17 | 0.07 | 56.0% |
| 5b. $\rho_{ini}A$–($U$-$U_0$) | 4.11 | 0.87 | 1.65 | 0.30 | -0.25 | 0.08 | 45.6% |

## 3.6 Expo-linear models

### 3.6.1 The models

The following expo-linear models were fitted to the data:

| | | |
|---|---|---|
| Model 6 | $N_{min,H} = a*N_{min,H,0} + (b/c) * \ln(1+ \exp(c*( A-A_{crit} -d)))$ | 3.11 |
| Model 7 | $N_{min,H} = a*N_{min,H,0} + (b/c) * \ln(1+ \exp(c*( A-(U-U_0) -d)))$ | 3.12 |
| Model 8 | $\Delta N_{min,H} = k + (b/c) * \ln(1+ \exp(c*( A-A_{crit} -d)))$ | 3.13 |
| Model 9 | $\Delta N_{min,H} = k + (b/c) * \ln(1+ \exp(c*( A-(U-U_0) -d)))$ | 3.14 |
| Model 6p | $N_{min,H} = a*N_{min,H,0} + (b/c) * \ln(1+ \exp(c*( A-A_{crit} -d))) + e P$ | 3.15 |
| Model 7p | $N_{min,H} = a*N_{min,H,0} + (b/c) * \ln(1+ \exp(c*( A-(U-U_0) -d))) + e P$ | 3.16 |
| Model 8p | $\Delta N_{min,H} = k + (b/c) * \ln(1+ \exp(c*( A-A_{crit} -d))) + e P$ | 3.17 |
| Model 9p | $\Delta N_{min,H} = k + (b/c) * \ln(1+ \exp(c*( A-(U-U_0) -d))) + e P$ | 3.18 |

where *a, b, e* and *k* are the linear regression coefficients and *c, d* the non-linear coefficients. $\Delta N_{min,H}$ is the difference between the experimental values of $N_{min,H}$ and $N_{min,H,0}$. All other variables are as in the earlier models (Paragraph 3.5.1).
Expolinear models have been introduced to describe crop growth (Goudriaan and Monteith , 1990) and their characteristic is that, after an exponential response of y to the independent x for low x-values, the slope approaches a fixed value (*b*) for larger values of x. Coefficient *c* is the relative rate of change of x in the exponential phase.

The expolinear pattern seems suitable to describe the response of $N_{min,H}$ to the selected 'normalised' N rate-variables, $A\text{-}A_{crit}$ and $A\text{-}(U\text{-}U_0)$. Its major advantage over other models is the constant slope of $N_{min,H}$ at 'saturating' N rates. At the same time, the above forms include the base level $N_{min,H,0}$ which was shown to be important in the previous paragraphs.

### 3.6.2 Results (non-weighted regression)

The results are given in Tables 3.9 and 3.10. Gaps in these tables indicate that no convergence could be obtained by the (GENSTAT) 'Fit-Non-linear' procedure used for this analysis, which implies that the data set does not allow the estimation of one or more model parameters.

The results show that the ($A\text{-}A_{crit}$)-form describes best the response in grass. Including precipitation *P* as extra regressor brings virtually no improvement.
In maize, both the ($A\text{-}A_{crit}$)-form and the $A\text{-}(U\text{-}U_0)$-form perform well, but only after including precipitation *P* in the model. The models with ΔNmin as response variable gave no result if $A\text{-}(U\text{-}U_0)$ was used as regressor, with or without *P*.

Based on these results, further analyses were restricted to the Models 6p and 7p only, which take $N_{min,H}$ as response variable and include precipitation as an explaining factor.

*Table 3.9. Percentage of variance accounted for ($R^2_{adjusted}$) and estimated parameter values for Models 6-9 and Models 6p-9p, for grass on sandy soils.*

| Grass | $R^2_{adj}$ | *b/c* | *b* | *c* | *d* | *a* or *k* | *e* |
|---|---|---|---|---|---|---|---|
| 6. $N_{min,H}$, $A$-$A_{crit}$ | 74.1 | 154.5 | 1.05 | 0.0068 | 392.4 | 0.83 | - |
| 7. $N_{min,H}$, $A$-($U$-$U_0$) | 59.4 | 58.6 | 1.00 | 0.0172 | 97.6 | 0.70 | - |
| 8. Δ $N_{min,H}$, $A$-$A_{crit}$ | 74.4 | 72.8 | 0.77 | 0.0106 | 291.1 | 3.72 | - |
| 9. Δ $N_{min,H}$, $A$-($U$-$U_0$) | - | - | - | - | - | - | - |
| 6p. + precipitation | 75.7 | 147.0 | 0.99 | 0.0068 | 373 | 0.83 | -0.0034 |
| 7p. + precipitation | 70.3 | 59.6 | 0.88 | 0.0147 | 29.9 | 1.37 | -0.092 |
| 8p. + precipitation | 75.3 | 77.9 | 0.78 | 0.0100 | 296.3 | 37.8 | -0.081 |
| 9p. + precipitation | 69.8 | 23.7 | 0.83 | 0.0351 | 48.8 | 53.9 | -0.124 |

*Table 3.10. Percentage of variance accounted for ($R^2_{adjusted}$) and estimated parameter values for Models 6-9 and Models 6p-9p, for maize on sandy soils.*

| Maize | $R^2_{adj}$ | *b/c* | *b* | *c* | *d* | *a* or *k* | *e* |
|---|---|---|---|---|---|---|---|
| 6. $N_{min,H}$, $A$-$A_{crit}$ | - | - | - | - | - | - | - |
| 7. $N_{min,H}$, $A$-($U$-$U_0$) | - | - | - | - | - | - | - |
| 8. Δ $N_{min,H}$, $A$-$A_{crit}$ | 53.5 | 2.7 | 0.43 | 0.161 | 19.0 | 0.63 | - |
| 9. Δ $N_{min,H}$, $A$-($U$-$U_0$) | - | - | - | - | - | - | - |
| 6p. + precipitation | 73.7 | 6.96 | 0.42 | 0.061 | 10.8 | 1.25 | -0.036 |
| 7p. + precipitation | 74.5 | 20.8 | 0.58 | 0.028 | -13.0 | 1.17 | -0.077 |
| 8p. + precipitation | 56.3 | 4.67 | 0.45 | 0.097 | 21.0 | 26.97 | -0.085 |
| 9p. + precipitation | - | - | - | - | - | - | - |

### 3.6.3 Results (weighted regression)

It was investigated how the increase in variance with increasing x-variate could be accounted for. This can be done by assigning weights which are a function of the difference $\varepsilon$ between the value of the fitted model ($y_m$) and the observation. First, a weight proportional to $y_m^{-2}$ was tried, but this proved to overestimate the response of variance to the x-variate. We then chose to take $(y_m + tiny)^{-1}$ as weight, where *tiny* is a small positive real to avoid division by zero. It was thus assumed that the variance is proportional to the function value $y_m$.

The results are shown in Tables 3.11 and 3.12. No dramatic effects of the regression method (weighted vs non-weighted) on the parameters are seen. The above pattern is confirmed here: the grass data are best decribed by the $A$-$A_{crit}$-model, whereas both the $A$-$A_{crit}$- form and the $A$-($U$-$U_0$)-form are well suited for the maize data.

An emerging difference between grass and maize is the consistently higher value of parameter *b* in grass, which suggests that at 'saturating' N rates a much larger proportion of incremental N doses are left as residual N in grass than in maize. (This occurs, however, at much higher N rates in grass than in maize). We cannot assess whether this difference is an artefact arising from the chosen upper range of N rates in the experiments.

*Table 3.11. Percentage of variance accounted for ($R^2_{adjusted}$) and estimated parameter values for Models 6p and 7p, with non-weighted and weighted regression for grass on sandy soils.*

| Grass | Non-weighted estimate | s.e. | Weighted estimate | s.e. |
|---|---|---|---|---|
| 6p. $A$-$A_{crit}$ | | | | |
| *b* | 0.985 | 0.313 | 0.915 | 0.282 |
| *c* | 0.0067 | 0.0017 | 0.0080 | 0.0017 |
| *d* | 373 | 109 | 343 | 89 |
| *a* | 0.83 | 0.22 | 1.05 | 0.14 |
| *e* | -0.0034 | 0.017 | -0.003 | 0.009 |
| $R^2_{adjusted}$ | 75.7% | | 72.0% | |
| 7p. $A$-($U$-$U_0$) | | | | |
| *b* | 0.875 | 0.115 | 0.947 | 0.150 |
| *c* | 0.0147 | 0.0060 | 0.0201 | 0.0083 |
| *d* | 29.9 | 31.5 | 67.9 | 24.4 |
| *a* | 1.37 | 0.30 | 1.37 | 0.19 |
| *e* | -0.092 | 0.033 | -0.037 | 0.016 |
| $R^2_{adjusted}$ | 70.3% | | 67.7% | |

*Table 3.12. Percentage of variance accounted for ($R^2_{adjusted}$) and estimated parameter values for Models 6p and 7p, with non-weighted and weighted regression for maize on sandy soils.*

| Maize | Non-weighted estimate | s.e. | Weighted estimate | s.e. |
|---|---|---|---|---|
| 6p. $A$-$A_{crit}$ | | | | |
| *b* | 0.422 | 0.038 | 0.419 | 0.037 |
| *c* | 0.0608 | 0.0763 | 0.094 | 0.122 |
| *d* | 10.8 | 14.5 | 29.0 | 10.3 |
| *a* | 1.25 | 0.07 | 1.23 | 0.059 |
| *e* | -0.036 | 0.011 | -0.013 | 0.005 |
| $R^2_{adjusted}$ | 73.7% | | 77.8% | |
| 7p. $A$-($U$-$U_0$) | | | | |
| *b* | 0.592 | 0.072 | 0.580 | 0.060 |
| *c* | 0.0284 | 0.0150 | 0.0496 | 0.0268 |
| *d* | -13.0 | 19.6 | 14.3 | 10.3 |
| *a* | 1.17 | 0.07 | 1.17 | 0.06 |
| *e* | -0.077 | 0.018 | -0.025 | 0.010 |
| $R^2_{adjusted}$ | 74.5% | | 76.8% | |

## 3.7 Confidence intervals of selected models

The 90%-confidence intervals for one linear model (2b) and one non-linear model (6p) were determined and are given in Figures 3.16-3.19. Model 2b was selected because of its practical significance, the surplus $A$-$U$ representing an easy-to-measure variable. Model 6p was chosen because it gave the best results on grass and maize combined, and because it is attractive for further modelling efforts, given its constant final slope. This property makes the model robust in more complex applications (whole farm modelling; uncertainty analyses), in contrast to models quadratic in the x-variate. Values chosen for the constants required to parameterize the models are given in Table 3.13. The values are considered representative of average conditions for grass and maize, respectively.

*Table 3.13. Values adopted for constants in Models 2b and 6p, to enable the calculation of model predictions and confidence intervals.*

| Variabele | gras | mais |
|---|---|---|
| $N_{min,H,0}$ (kg N ha$^{-1}$) | 20 | 30 |
| Precipitation (mm) | 450 | 345 |
| $A_{crit}$ [1] | 265 | 40 |
| N rate ($A$) [1] | 0 to 500 | 0 to 200 |
| Surplus ($A$-$U$) [2] | -200 to +200 | -100 to +100 |
| $A$-$A_{crit}$ [1] | -265 to 235 | -40 to +160 |

[1]. *applies to Model 6p only;* [2] *applies to Model 2b only*

Note that the graphs show both the confidence interval for the regression curve, and for new individual predictions. The latter is, obviously, much wider, and this is a measure of the uncertainty we are dealing with when the model is applied under any new set of conditions.
The confidence interval (new prediction) is slightly larger for the surplus based linear model than for the expolinear model. On average, an $N_{min,H}$-level of 40 kg N ha$^{-1}$ is reached at N rates of about 400 kg ha$^{-1}$ in grass and 100 kg ha$^{-1}$ in maize (bold lines in graphs, Figs. 3.16, 3.17). This corresponds, according to the N-surplus based model, with an N surplus of values of about –70 kg ha$^{-1}$ in grass, and –100 kg ha$^{-1}$ in maize (bold lines in graphs, Figs. 3.18, 3.19). It is stressed again that the surplus is based on effective N input only; the relations should apply, therefore, to mineral fertilisers as well as animal manures. The surplus value based on total N input is obviously higher with animal manures than with fertilisers, at the same N rate.

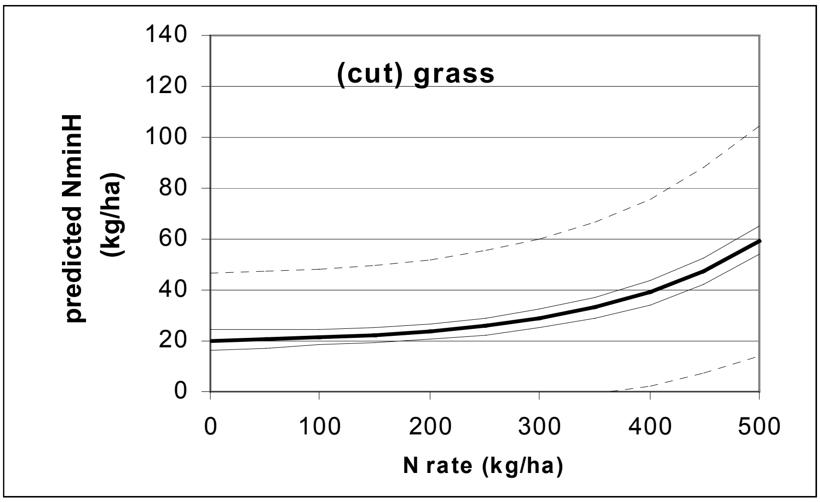



*Figure 3.16. Prediction of the response of $N_{min,H}$ to N rate in (cut) grass (bold line), according to the $A_{crit}$-based expo-linear model (Model 6p). The 90% confidence interval for the regression line is indicated in solid lines; the 90% confidence interval for a prediction under a new set of conditions is given in broken lines. The confidence intervals increase with N rate. Values presumed for constants are listed in Table 3.13.*

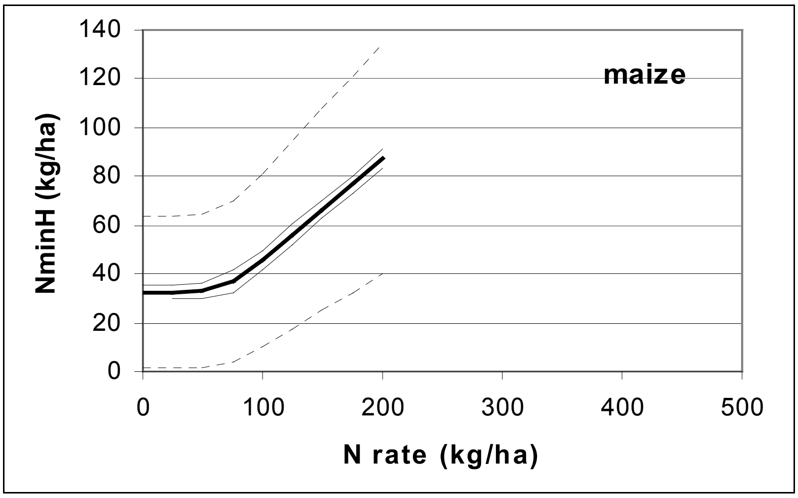



*Figure 3.17. Prediction of the response of $N_{min,H}$ to N rate in maize (bold line), according to the $A_{crit}$-based expo-linear model (Model 6p). The 90% confidence interval for the regression line is indicated in solid lines; the 90% confidence interval for a prediction under a new set of conditions is given in broken lines. The confidence intervals increase with N rate. Values presumed for constants are listed in Table 3.13.*

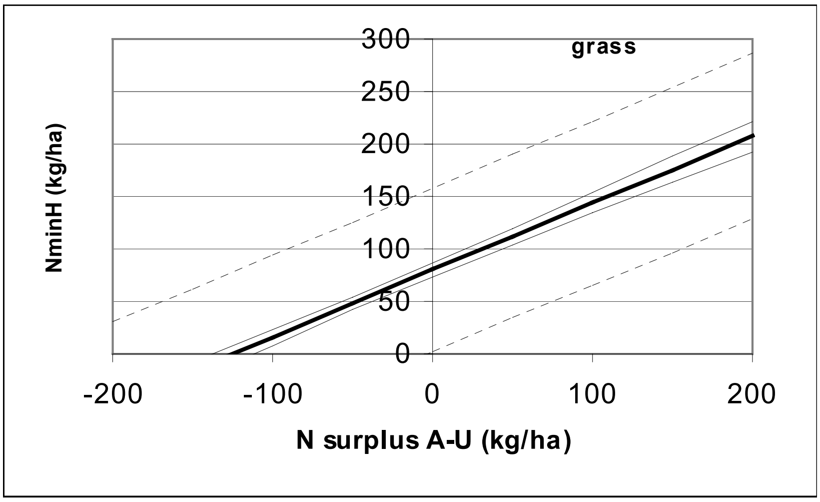



*Figure 3.18. Prediction of the response of $N_{min,H}$ to N rate in grass (bold line), based on the linear surplus model (Model 2b). The 90% confidence interval for the regression line is indicated in solid lines; the 90% confidence interval for a prediction under a new set of conditions is given in broken lines. In calculating the surplus, only the effective N rate (not total N input) was taken as N input. The graph therefore applies to both fertiliser and animal manures. Values presumed for constants are listed in Table 3.13.*

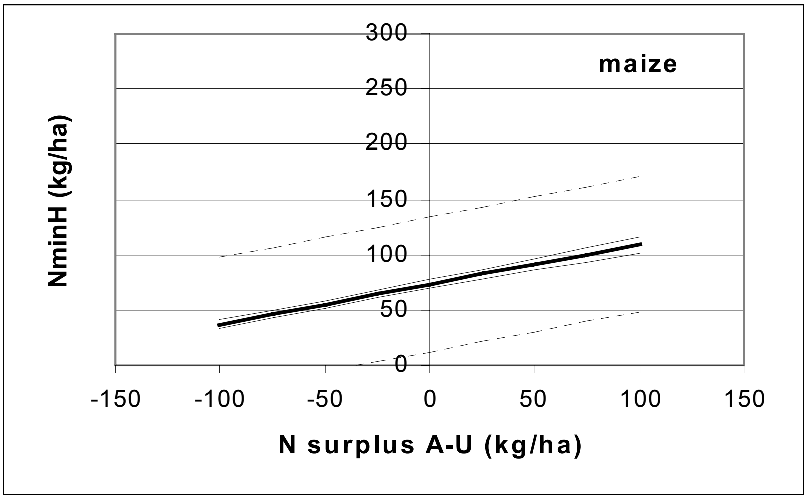



*Figure 3.19. Prediction of the response of $N_{min,H}$ to N rate in maize (bold line), based on the linear surplus model (Model 2b). The 90% confidence interval for the regression line is indicated in solid lines; the 90% confidence interval for a prediction under a new set of conditions is given in broken lines. In calculating the surplus, only the effective N rate (not total N input) was taken as N input. The graph therefore applies to both fertiliser and animal manures. Values presumed for constants are listed in Table 3.13.*

## 3.8 QUADMOD parameterisation for $N_{min,H}$ models

### 3.8.1 Purpose

In this paragraph we apply the QUADMOD concept to the modelling of $N_{min,H}$. QUADMOD is essentially only a parameterisation of crop responses (biomass yield and N yield) to applied N rates, but it provides a useful frame in the present context. As mentioned earlier, this descriptive model is invoked here with the following purposes:

i to quantify crop-specific characteristics that determine N yield in response to N rate; based on these, crop N yields can be estimated for new conditions as is required in any application of surplus-based expressions;

ii to assess for each given data set the critical N rate (see Chapter 2) which is required as parameter in some of the regression models;

iii to evaluate Eq. 2.11 (Chapter 2), on the basis of observed crop responses (biomass yield and N yield) for a larger range of crops

For details on the QUADMOD model, the reader is referred to Ten Berge *et al.* (2000). The model is summarized below in Figure 3.20, and the seven independent model parameters are defined in Table 3.14.

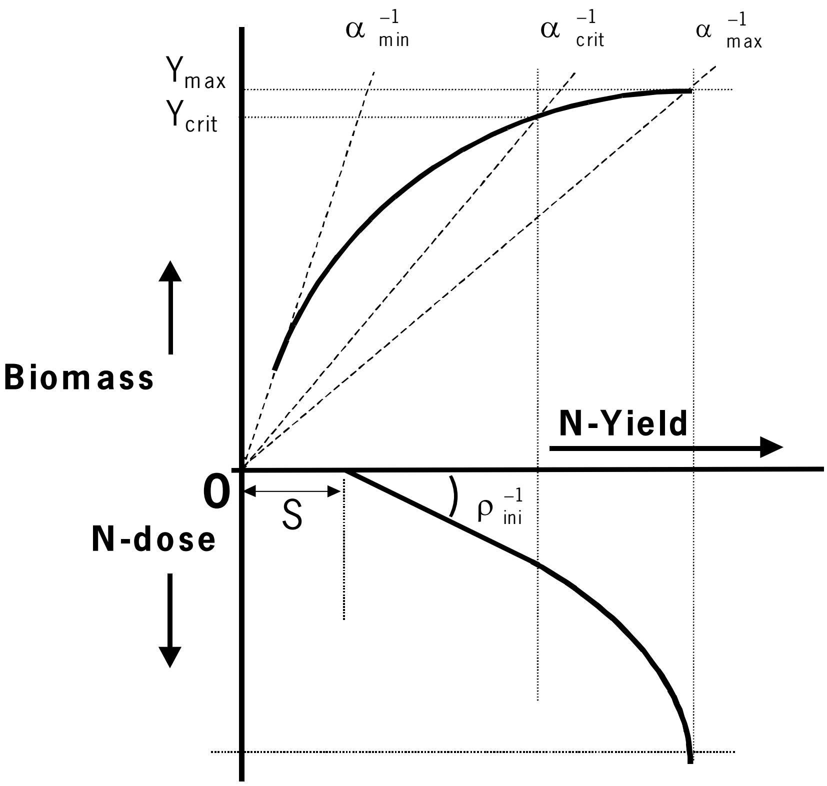



*Figure 3.20. Graphical representation of the QUADMOD model.*

*Table 3.14. The parameters of the QUADMOD core model, describing the response of N-yield (U, kg N ha$^{-1}$) to N-dose (A, kg N ha$^{-1}$) and the response of biomass DM-yield Y (kg/ha) to N-yield.*

| Name | Definition | Unit |
|---|---|---|
| $Y_{max}$ | maximum biomass dry matter (DM) yield | kg DM ha$^{-1}$ |
| $\gamma$ | relative biomass yield at critical point (= $Y_{crit}/Y_{max}$) | - |
| $\alpha_{min}$ | minimum N-concentration in biomass | kg N $kg_{DM}^{-1}$ |
| $\alpha_{crit}$ | N-concentration in biomass at critical point | kg N $kg_{DM}^{-1}$ |
| $\alpha_{max}$ | maximum N-concentration in biomass | kg N $kg_{DM}^{-1}$ |
| $\rho_{ini}$ | apparent initial fertiliser-N recovery. i.e., apparent recovery under low N-availability | kg N $kg_{N}^{-1}$ |
| $S$ | uptake of N supplied from soil, i.e., N-yield on non-fertilised plots | kg N ha$^{-1}$ |

### 3.8.2 Data sets

The model parameters were determined by parameter optimisation, on the basis of the experimental data sets listed in Table 3.15. These data complement, for the purpose of this study, a larger number of sets analysed earlier (Ten Berge *et al.*, 2000). The procedure to assess the parameter values is a numerical random search global optimisation algorithm, which optimizes all parameters to find the best match between the model and observed values of N-yield and biomass yield, simultaneously. Obviously, no information on $N_{min,H}$ is used in optimizing the model parameters.

*Table 3.1.5. Data sets used to determine QUADMOD parameters from N-response trials.*

| Crops | Soil | # Sets | Years | Source |
|---|---|---|---|---|
| Cauliflower | Clay | 8 | 90,92 | Everaarts, 1995 |
| Broccoli | Clay | 8 | 90-92 | Everaarts, 1995 |
| Potatoes ware | Clay | 16 | 87-90 | Hengsdijk, 1992; Titulaer, 1997, Van Loon, 1998; Anon., 1999 |
| Potatoes starch | Sand | 37 | 91-97 | Van Loon, 1995; Wijnholds, 1995, 1996, 1997 |
| | Reclaimed peat | 11 | 88-93 | Van Loon, 1995; Postma, 1995; Anon., 1999 |
| Iceberg lettuce | Clay | 5 | 85,86 | Anon., 1999 |
| Iceberg lettuce | Sand | 15 | 85-87 | Slangen, 1989, Anon., 1999 |
| Leek | Sand | 3 | 90-92 | Anon., 1999; Geel, 2000 |
| Spinach | Clay | 6 | 94-96 | De Kraker, 1997 |
| Sugarbeet | Clay | 24 | 87-91 | Hengsdijk, 1992; Westerdijk, 1992; Van Dijk, 1999; Anon., 1999 |
| | sand | 1 | 89 | Anon., 1999 |
| Winter wheat | Clay | 5 | 94-98 | Darwinkel, 2000; Anon.,1999; Timmer, 1999 |
| | Loess | 4 | 95-98 | Geelen, 1999 |
| Witloof chicory | Clay | 2 | 88-94 | Van Kruistum, 1997; Schober, 1998; Anon., 1999 |
| | Loess | 2 | 91,93 | Postma, 1995 |
| White cabbage | Clay | 8 | 92-93 | Everaarts, 1995 |
| Seed onion | Clay | 8 | 89-94 | De Visser, 1996; Anon.,1999 |
| Digitalis | Clay | 4 | 89-92 | Anon. 1999 |
| Barley | Clay | 3 | 96-98 | Anon. 1999 |
| Brew barley | Sand | 3 | 96-98 | Anon. 1999 |
| Brew barley | Clay | 6 | 96-98 | Anon. 1999 |
| Summer barley | Clay | 4 | 92-95 | Anon. 1999 |
| Miscanthus | Reclaimed peat | 2 | 94-95 | Anon. 1999 |
| | Clay | 2 | 94-95 | Anon. 1999 |
| | Loess | 2 | 94-95 | Anon. 1999 |

### 3.8.3 Results : QUADMOD parameters for crops

The results are given in Table 3.16.

*Table 3.16. Mean values of QUADMOD parameters per crop. The number of valid datasets (n) varies between parameters because the N-supply range covered in the experiment must include observations at low and high N-supply for sets to qualify for the assessment of all seven parameters. See text for validity criteria. cv refers to the coefficient of variation of the sample. Grass and maize parameters were taken from Ten Berge et al. (2000) and refer to sand soils.*

| | $S$ | | | $\rho_{ini}$ | | $\alpha_{min}$ | | | $\alpha_{crit}$ | | $\gamma$ | | | $\alpha_{max}$ | | $Y_{max}$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *cv* | *n* | | *cv* | | *cv* | N | | *cv* | | *cv* | *n* | | *cv* | | *cv* | *n* |
| Cut grass | 206 | *0.15* | *70* | 0.90 | *0.10* | 0.023 | *0.10* | *65* | 0.030 | *0.11* | 0.88 | *0.11* | *49* | 0.041 | *0.05* | 14020 | *0.15* | *54* |
| Maize | 88 | *0.28* | *14* | 0.72 | *0.31* | 0.007 | *0.28* | *11* | 0.010 | *0.08* | 0.86 | *0.08* | *8* | 0.013 | *0.05* | 14080 | *0.12* | *9* |
| Cauliflower | 80 | *0.24* | *8* | 0.34 | *0.19* | 0.018 | *0.11* | *2* | 0.026 | *0.33* | 0.99 | *0.001* | *2* | 0.040 | *0.10* | 2959 | *0.14* | *8* |
| Broccoli | 26 | *0.20* | *8* | 0.16 | *0.25* | 0.033 | *0.08* | *8* | 0.042 | *0.06* | 0.93 | *0.08* | *6* | 0.045 | *0.06* | 1121 | *0.26* | *6* |
| White cabbage | 67 | *0.19* | *8* | 0.46 | *0.07* | 0.010 | *0.14* | *8* | 0.017 | *0.14* | 0.96 | *0.08* | *5* | 0.022 | *0.16* | 8554 | *0.12* | *5* |
| Potato (ware) | 129 | *0.20* | *16* | 0.50 | *0.57* | 0.008 | *0.13* | *5* | 0.014 | *0.04* | 1.00 | *0.00* | *2* | 0.016 | *0.08* | 14201 | *0.06* | *12* |
| Potato (starch) | 118 | *0.30* | *11* | 0.54 | *0.16* | 0.006 | *0.07* | *2* | - | - | - | - | *0* | 0.012 | *0.09* | 14092 | *0.26* | *7* |
| Iceberg lettuce | 45 | *0.46* | *19* | 0.61 | *0.55* | 0.021 | *0.23* | *5* | 0.026 | *0.17* | 0.91 | *0.09* | *3* | 0.036 | *0.11* | 2154 | *0.19* | *15* |
| Witloof chicory | 73 | *0.55* | *4* | 0.18 | - | 0.004 | - | *1* | 0.008 | - | 0.99 | - | *1* | 0.014 | *0.11* | 8617 | *0.17* | *3* |
| Sugar beet[1] | 62 | *0.26* | *27* | 0.54 | *0.49* | 0.005 | *0.26* | *10* | 0.0069 | *0.37* | 0.99 | *0.001* | *5* | 0.0074[2] | *0.35* | 16510 | *0.19* | *12* |
| Barley (brew.) | 76 | *0.31* | *9* | 0.51 | *0.17* | 0.012 | *0.21* | *3* | 0.015 | *0.16* | 0.94 | *0.04* | *2* | 0.017 | *0.10* | 6781 | *0.09* | *8* |
| digitalis | 75 | *0.52* | *4* | 0.37 | *0.22* | 0.013 | *0.14* | *2* | 0.017 | - | 0.80 | - | *1* | 0.025 | *0.03* | 6729 | *0.24* | *3* |
| Leek | 121 | *0.46* | *6* | 0.38 | *0.47* | 0.022 | *0.63* | *2* | 0.025 | *0.49* | 0.98 | *0.03* | *2* | 0.035 | *0.17* | 5241 | *0.13* | *3* |
| Winter wheat[3] | 90 | *0.26* | *11* | 0.68 | *0.25* | 0.012 | *0.12* | *9* | 0.019 | *0.21* | 0.89 | *0.18* | *2* | 0.024 | *0.17* | 8726 | *0.08* | *4* |
| Seed onion | 105 | *0.22* | *8* | 0.38 | *0.30* | 0.009 | *0.19* | *3* | 0.014[4] | - | 0.95[4] | - | *0* | 0.021 | *0.39* | 9042 | *0.26* | *3* |
| Spinach | 60 | *0.61* | *6* | 0.19 | *0.45* | 0.036 | *0.26* | *3* | 0.048 | - | 1.00 | - | *1* | 0.052 | *0.08* | 1899 | *0.28* | *3* |

[1] *parameters refer to only beet root*
[2] *observed N-concentrations upto 0.012 in sugar beet*
[3] *parameters refer to grain only*
[4] *mean of all sets, but no sim.match of both validity criteria*

### 3.8.4 Evaluation of Eq 2.11

In this paragraph we attempt to model $N_{min,H}$ by straightforward application of Eq. 2.11 – that is, using the straight balance expression without incurring regression on $N_{min,H}$ data. This would enable to predict $N_{min,H}$ responses directly from crop properties, thus avoiding the need to parameterise regression models which require sufficiently large sets of $N_{min,H}$ observations.

QUADMOD parameter values obtained for the respective crops (Table 3.16; also from Ten Berge *et al.*, 2000) were used to quantify the coefficient associated with the quadratic term in Eq. 2.11 (Chapter 2). This coefficient can be expressed in 'primary' QUADMOD parameters according to:

$$\mu \equiv \frac{\rho_{ini}}{2\left[A_{\max} - A_{crit}\right]} = \frac{\rho_{ini}^2}{4Y_{\max}\left[\alpha_{\max} - \gamma\alpha_{crit}\right]} \qquad 3.19$$

Note that no information on observed $N_{min,H}$ was used in this modelling attempt. The figures below show the comparison between these calculated curves and the actual $N_{min,H}$ observations. The results for grass and maize are considered reasonablye good. $N_{min,H}$ in the vegetable crops, however, is described with varying success by this simplified approach.

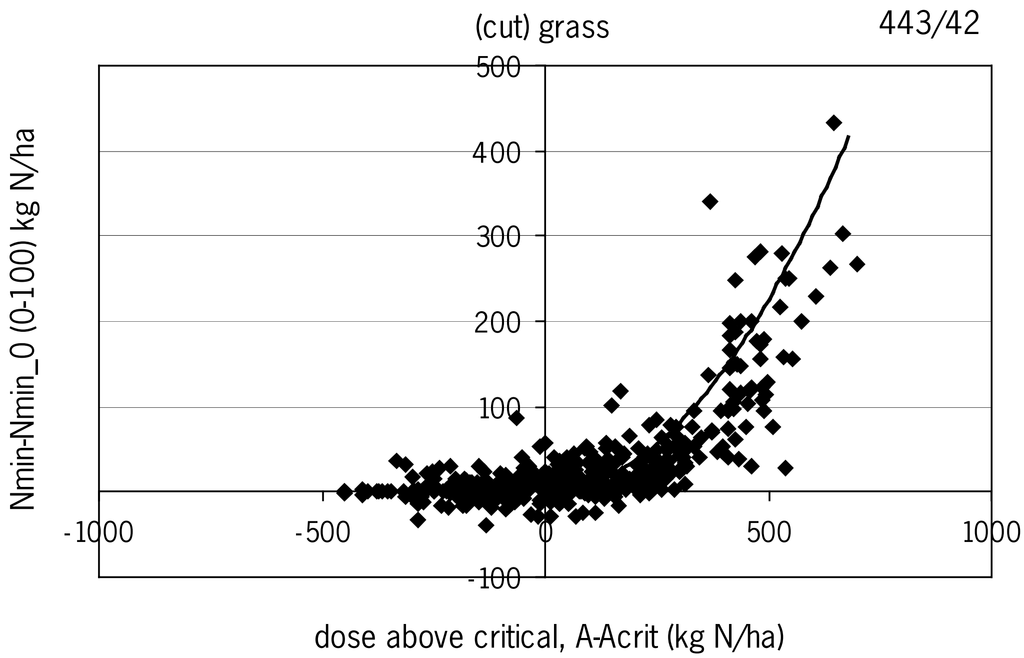



*Figure 3.21. Increment in residual soil N (0-100 cm) at the last cut harvest ($N_{min,H}$) in grass, relative to residual soil N observed at the same time in plots that received no N input ($N_{min,H,0}$), versus the amount by which the applied N rate exceeds the critical N rate, $A_{crit}$. The values of $N_{min,H,0}$ and $A_{crit}$ are case-specific: they vary with the location and the year of the experiment. All grass data listed in Table 3.1 are included. The plotted curve expresses Eq. 2.11 with $\mu$ = 0.000924 ha kg$^{-1}$ according to Eq. 3.19 and grass parameters from Ten Berge et al. (2000).*

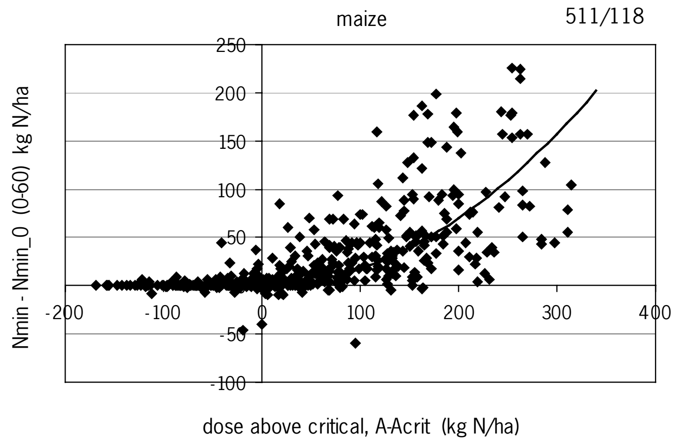



*Figure 3.22.* *Increment in residual soil N (0-60 cm) at harvest ($N_{min,H}$) in maize, relative to residual soil N observed at the same time in plots that received no N input ($N_{min,H,0}$), versus the amount by which the applied N rate exceeds the critical N rate, $A_{crit}$. The values of $N_{min,H,0}$ and $A_{crit}$ are case-specific: they vary with the location and the year of the experiment. All maize data listed in Table 3.1 are included. The plotted curve expresses Eq. 2.11 with $\mu$ = 0.00175 ha $kg^{-1}$ according to Eq. 3.19 and maize parameters from Ten Berge et al. (2000).*

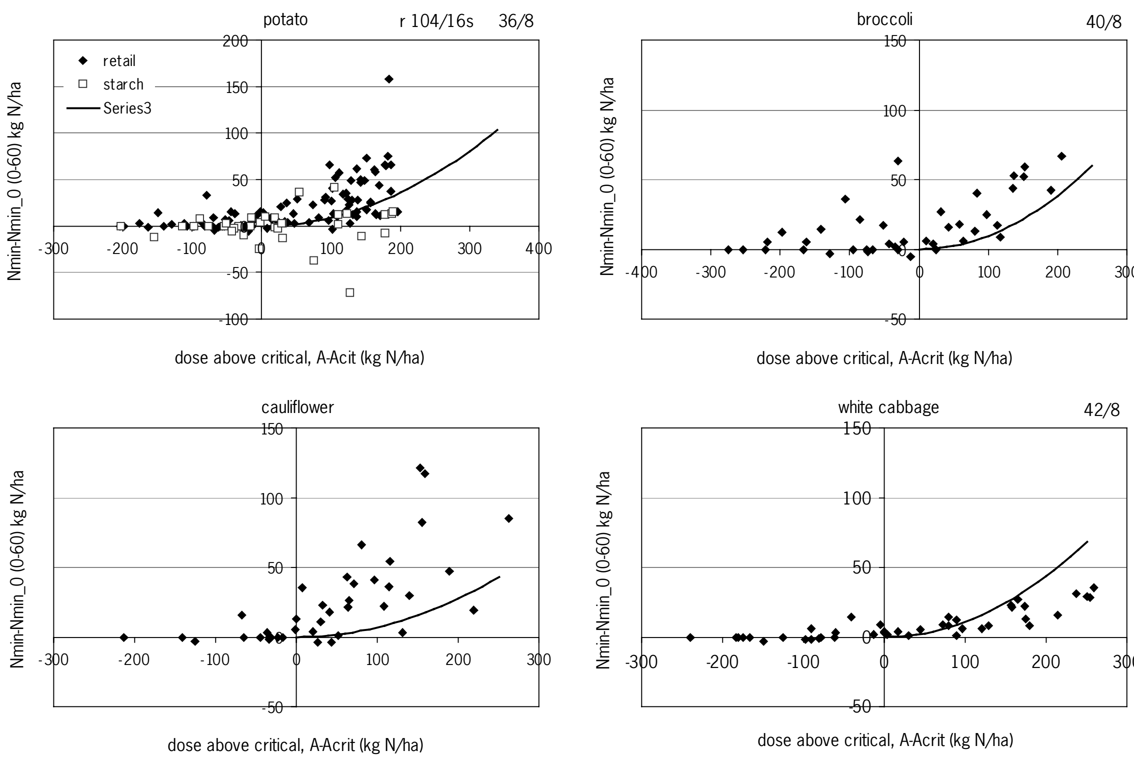



*Figure 3.23.* *Increment in residual soil N (0-60 cm) at harvest ($N_{min,H}$), relative to residual soil N observed at the same time in plots that received no N input ($N_{min,H,0}$) versus the amount by which the applied N rate exceeds the critical rate, $A_{crit}$. For potato, broccoli, cauliflower and white cabbage. Data for the latter three crops refer to clay soils only. The plotted curves express Eq. 2.11 with $\mu$ calculated from Table 3.16 with the help of Eq. 3.19.*

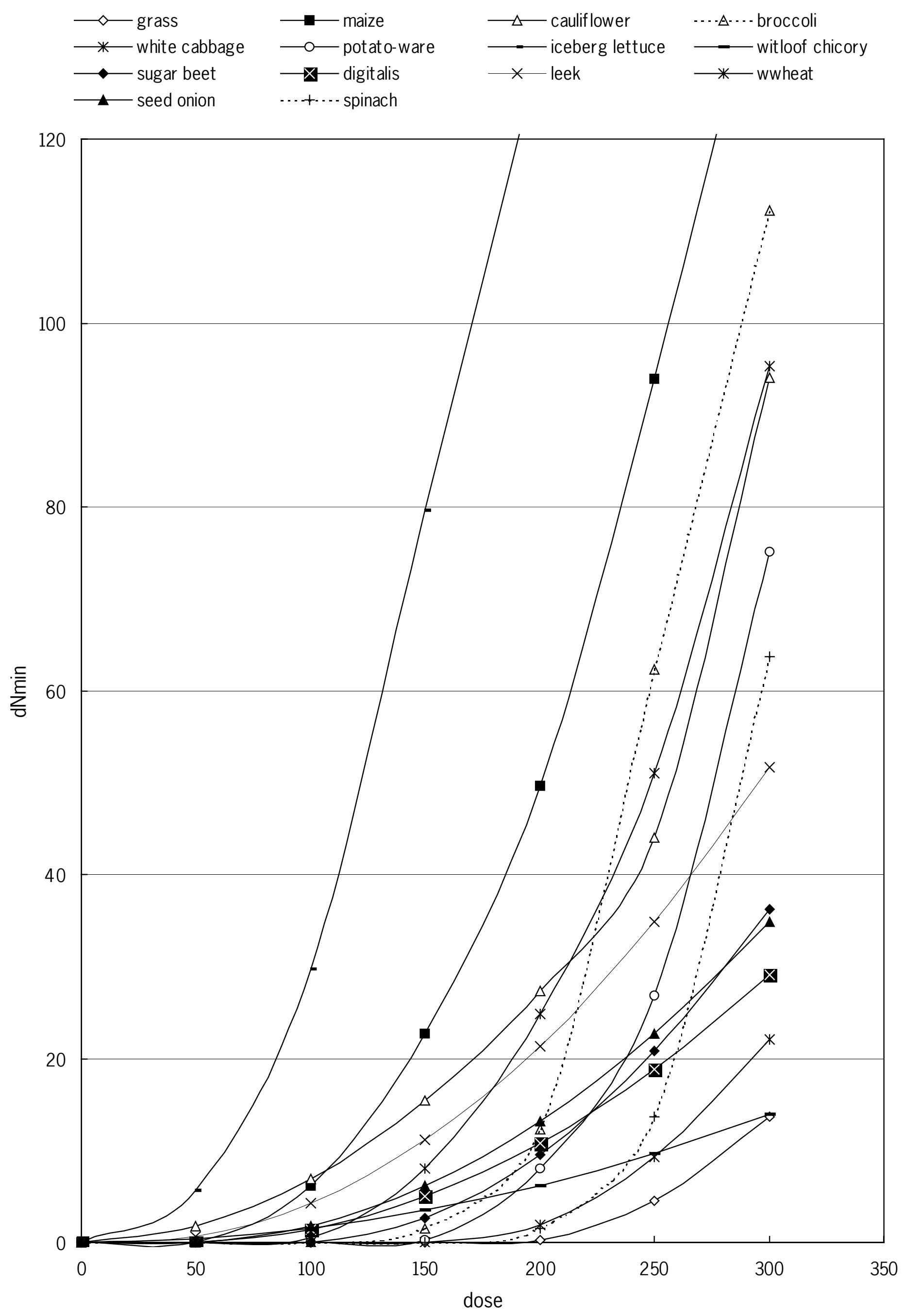



*Figure 3.24. Calculated responses of $N_{min,H}$ to N rate, based on Eq. 3.19 and Table 3.16; for a range of crops.*

### 3.8.5 The relation between (*A-U*) and (*A-A*$_{crit}$)

The crop N-uptake observed under zero-N input, $U_0$, has been included explicitly in some of the composed regressors introduced earlier, while it is 'hidden' in others, for instance in the surplus (*A-U*), because $U_0$ affects *U* at given input *A*. We investigate in this paragraph the role that $U_0$ plays in relating two important regressors, namely (*A-U*) and ($A$-$A_{crit}$), and we will attempt to evaluate how changes in this parameter will affect the relations between these regressors, and the relations with $N_{min,H}$.

The value of $U_0$ is determined to some extent by inherent soil properties (texture, drainage) and annual weather conditions, but is largely affected by the long term history of management, that is, the annual net inputs of organic matter and nitrogen. This is why considerable variation exists in $U_0$, both in space and in time.

The effect of $U_0$ on crop N yield can be expressed by a relation introduced earlier (Chapter 2), and which was adopted from the QUADMOD model:

$$U = U_0 + \rho_{ini}\, A - \mu\, (A - A_{crit})^2 \qquad 3.20$$

where the last term vanishes for $A < A_{crit}$ ; the coefficient $\mu$ is defined as in Eq. 3.19

The relation between the applied N rate $A$ and the surplus $A$-$U$ follows from Eq 3.20

$$A - U = (1 - \rho_{ini})\, A - U_0 + \mu\, (A - A_{crit})^2 \qquad 3.21$$

and this gives also the connection between the surplus and $A$-$A_{crit}$.
We suppose here that the accumulation of residual mineral N in soils is indeed directly related to the amount by which the N rate exceeds the critical rate $A_{crit}$, as suggested by the results presented earlier in this report. Variations in $U_0$ will then not affect that relation between $N_{min,H}$ and ($A$-$A_{crit}$), but will affect the critical rate itself, according to:

$$A_{crit} = \frac{U_{crit} - U_0}{\rho_{ini}} \qquad 3.22$$

where $U_{crit} \equiv \gamma\alpha_{crit}\, Y_{max}$ is independent of $U_0$, as is $\rho_{ini}$.
Eqs. 3.21, 3.22 enable to assess whether the relation between ($A$-$U$) and $N_{min,H}$ shares this independence with respect to $U_0$. That would only be so if changes in the first two right hand side terms in 3.21, resulting from changes in $U_0$, would offset each other. We maintain in this exercise that the primary determinant for $N_{min,H}$ is $A$-$A_{crit}$. Now if, for a given fixed value of $A$-$A_{crit}$, $U_0$ changed by an increment $+\Delta U_0$, $A_{crit}$ would change according to Eq 3.22 by an amount $-\Delta U_0/\rho_{ini}$. At constant $A$-$A_{crit}$, this implies that $A$, too, would change by an amount $-\Delta U_0/\rho_{ini}$ and as a consequence, the term $(1-\rho_{ini})A$ changes by $-\Delta U_0(1-\rho_{ini})/\rho_{ini}$. This would only cancel out the increment $+\Delta U_0$ of the second term in the special case where $\rho_{ini} = 0.5$. The conclusion is that, at given $A$-$A_{crit}$, $A$-$U$ may attain a range of different values depending on $U_0$. This explains the often poor correlation found between surplus and $N_{min,H}$ if data stem from experiments (years, sites) with different $U_0$. It also implies that the relation between surplus and $N_{min,H}$ will gradually change if $U_0$ changes due to long term accumulation or breakdown of organic soil N reserves.

Eq. 3.21 also allows to assess the 'safe' surplus value in function of $U_0$, if we presume again that positive values of A-Acrit are required to build up $N_{min,H}$. At $A$=$A_{crit}$, the surplus follows from Eqs 3.21 and 3.22 as

$$A - U = \frac{(1 - \rho_{ini})\; U_{crit} - U_0}{\rho_{ini}} \qquad 3.23$$

It is obvious that this surplus value can be positive as well as negative, depending on the soil fertility level expressed in $U_0$, relative to the crop demand $U_{crit}$ which is largely defined by the yield potential under the local circumstances, $Y_{max}$, and the crop characteristic N-concentration at the critical point, $\alpha_{crit}$. This is also what we have observed from the empirical analysis earlier in this chapter, and it is indeed a serious drawback of the surplus ($A$-$U$) as indicator for potential nitrate losses.

In summary, it is postulated here that relations for $N_{min,H}$ based on ($A$-$A_{crit}$) as regressor will not be altered due to changes in $U_0$– whether arising from long term developments in $U_0$ or from (spatial) differences between soils. Instead, the value of $A_{crit}$ changes in function of $U_0$. The surplus ($A$-$U$) is poorly correlated with $N_{min,H}$, largely because variation exists in the parameter $U_0$. For an indication of the range of variation that may occur in $U_0$, we refer to Fig. 3.10 earlier in this chapter.
It can be argued on good grounds, however, that the value of $U_0$ will adjust in the long run to the chosen N management, and that the variation found in $U_0$ today across all experimental datasets is much larger - and the correlation between $N_{min,H}$ and surplus poorer – than after a period of equilibration. An attempt is therefore made in the next paragraph to look at the system in a state of pseudo-equilibrium.

## 3.9 Long term equilibration of $U_0$, and its effects on relations between $N_{min,H}$ and selected regressors

The soil fertility parameter $U_0$ adjusts itself over the years to the specific management practices, notably N input levels and N species, and after several decades of maintaining these practices will a 'pseudo steady state' be reached when the (upward or downward) drift in $U_0$ has faded. This equilibrium situation is rarely found under experimental conditions. More than anywhere, this is true of N response trials: the very introduction of graded N rates applied to different plots all sharing one and the same initial $U_0$ value implies that – at most, and accidentally – only one of the chosen rates might be in steady state equilibrium with the existing soil conditions. The entire database presented and used in this report is subject to this inconsistency. On the one hand, this does not invalidate our analyses, because it requires many years (decades) for soils to adjust to management and hence the relations established upon existing empirical data would remain valid for some time. Moreover, some variation in $U_0$ will always remain due to annual weather conditions. On the other hand, the noise in some of our relations may be inflated due to the absence of 'consistency' between N input and $U_0$ in the data sets, especially in view of the extreme N rates usually employed in N response trials.

For a first approximation of the relation between $U_0$ and N management, we use the simplest possible model of organic matter decay. Since the early 19th century (Thaer, 1809; Von Wulffen 1823; 1830; 1847; summarized by De Wit, 1974) it has been known that the build-up – or decline - of soil fertility is the net result of two opposing fluxes: the annual inputs brought into the soil system, and the liberation and subsequent uptake of nutrients from the stock contained in the soil. Von Wulffen expressed this release as a fixed fraction, annually, of the total stock, and introduced the concept that an equilibrium state should finally be approached if the annual input remained constant during many years. This state was referred to as the 'Beharrungspunkt' and it was also recognized that the corresponding fertility level would be high in systems where the annual fraction released ($\tau$, $y^{-1}$) was small, and low where this coefficient was large. Von Wulffen's analysis was based on elaboration of numerous empirical long-term records of crop yields, and his first order approach still stands, be it of old age and approximative, as a robust model of organic matter-related soil fertility development. The approach can be formalised as below.

Let $I_r$ denote the annual input of organic nitrogen that is not readily accessible for plant uptake in the first year upon application. This fraction has been referred to as 'resistant' organic nitrogen, $N_r$, and the total pool of this N-form in the soil system is written as $N_r$. For the rate of change of this pool we can write

$$\frac{dN_r}{dt} = +I_r - \tau(N_r + I_r) \qquad 3.24$$

with $t$ for time, and $\tau$ the relative decay rate (year$^{-1}$), representing the fraction of the pool that is mineralised every year. Solving this gives

$$N_r = \frac{I(1-\tau)}{\tau} + \left( N_{r,0} - \frac{I(1-\tau)}{\tau} \right) e^{-t\tau} \qquad 3.25$$
$$= N_{r,\infty} - (N_{r,\infty} - N_{r,0})\, e^{-t\tau}$$

with $N_{r,\infty}$ for the pool size at time infinity, and $N_{r,0}$ for the initial pool size at $t$=0. The annual decay or release rate $M$ is then

$$M = \tau(I_r + N_r) \qquad 3.26$$

Combining Eqs 3.7 and 3.8 gives

$$M = I_r + \tau(N_{r,0} - N_{r,\infty})\, e^{-t\tau} \qquad 3.27$$

This expression shows that the value of $M$ approaches $I_r$ for large values of $t$ , and that the annual release is larger than $I_r$ when the intial state of the soil, $N_{r,0}$ , is 'richer' than the state $N_{r,\infty}$ corresponding ultimately to $I_r$ - as is the case in the Netherlands where allowed N-surpluses are increasingly tightened under the implementation of MINAS.

Today it is obvious that Eqs 3.24-3.27 are a simplification, because in reality the breakdown coefficient $\tau$ itself is a function of time as it depends on the quality– and thereby the age - of the organic N-compounds contained in the pool. It is therefore difficult to reproduce, with a single constant $\tau$-value, observed time patterns of $M$ or $N_r$. A few conclusions, however, can safely be drawn which are of direct relevance to our case:

(i) under any given level of annual input $I_r$, both the total pool of organic soil N and the annual N-release from this pool by mineralisation should in the long run approach constant values, such that the amount of N released per year is almost equal to the net annual N input into the soil pool, that is, N-input after subtraction of crop offtake and N-losses not captured into organic matter;

(ii) for a $\tau$-value of 0.01 $y^{-1}$, for example, the 'half life' required to bridge half the gap between the initial and final pool sizes, $N_{r,0}$ and $N_{r,\infty}$ respectively, would be 70 years, based on Eq. 3.25. For $\tau$=0.05, this would reduce to 14 years, and most authors presume time coefficients for organic matter decay in between these two values. Depending on the change in input $I_r$ imposed at $t$=0, this may have a strong bearing on the annual release rate $M$, according to Eq. 3.27.

The parameter $U_0$ is not identical with the annual mineralisation $M$, but is obviously closely related. $U_0$ includes – in addition to N derived from mineralisation of organic matter – also N derived from atmospheric deposition. On the other hand, not all N that becomes available from these two sources is actually captured in harvested crop parts and would thus be included in the value of $U_0$. Let this fraction captured be written as $q_1$, and the annual deposition as d (approximately 50 kg N/ha/y in the Netherlands) of which amount a fraction $q_2$ is intercepted by the crop. It follows that the parameter $U_0$, once equilibrated to long-term constant input, is then given by

$$U_{0,\infty} = q_1\, I_r + q_2 d \qquad 3.28$$

The annual input $I_r$ is a function of the applied N rate $A$ but, obviously, also of the forms in which N is supplied, in other words the ratio of N in animal manures to N in mineral fertilisers, and the properties of the manure:

$$I_r = A \cdot \left( \frac{f\beta}{w} + r(1-\rho) \right) \qquad 3.29$$

where $f$ is the fraction of the total effective-N dose $A$ that is supplied in the form of animal manure, $\beta$ is the fraction of manure-N which is in the form of $N_r$ (estimated at 0.3 in cattle slurry); $w$ is the 'working coefficient' or fraction of N in animal manure that is as effective – in terms of crop uptake - as mineral fertiliser. The first term in brackets thus represents the external $N_r$-input. In the second term, (1-$\rho$) represents the amount of effective N (both from fertiliser and manure sources) that is not recovered in harvested crop parts, a fraction $r$ of which is not really lost from the soil system but converted into $N_r$. Little is known about the fate of non-recovered N, and the two extremes for *r* would be 0 (no N retained as $N_r$) to 1 (all N retained as $N_r$). (For $A < A_{crit}$, $\rho$ would be equal to $\rho_{ini}$.)

Continued application of large amounts of $N_r$ will, if maintained over decades, increase soil fertility parameter $U_0$ and thereby reduce the threshold dose $A_{crit}$ which is taken here as the safely permissible N-dose precluding the build-up of $N_{min,H}$. This dose was defined by Eq. 3.22. By substituting $A_{crit}$ for $A$ in Eq. 3.11, and then introducing Eqs 3.28 and 3.29 into Eq 3.22, we can now express the permissible dose in the equilibrium state, $A_{crit,\infty}$ , in function of the parameters in Eq 3.29:

$$A_{crit,\infty} = \frac{U_{crit} - U_{0,\infty}}{\rho_{ini}} = \frac{\gamma\alpha_{crit}\, Y_{max} - q_2 d}{\rho_{ini} + q_1\zeta} \qquad 3.30$$

where $\zeta$ represents the term in brackets in Eq. 3.29. Note that $A_{crit,\infty}$ as defined by Eq 3.30 corresponds to the situation where precisely this same level $A= A_{crit,\infty}$ has been maintained as the annual input.

One could argue, based on the results of the earlier regression analysis, that an N rate $A_x$ somewhat higher than $A_{crit}$ could be allowed before $N_{min,H}$ passes a given threshold. The values of $U_{0,\infty}$ and $A_{crit,\infty}$ that would correspond to this $A_x$ ($>A_{crit}$) can be calculated based on the above expressions but that is slightly more complex and the derivation is omitted here.

From 3.28 and 3.29 with 3.30, it follows that the $U_0$ value that corresponds in the long run with the annual N-input as defined by Eq 3.30, is given as

$$U_{0,\infty} = q_1 \left[\frac{\gamma\alpha_{crit}\, Y_{max} - q_2 d}{\rho_{ini} + q_1\zeta}\zeta\right] + q_2 d \qquad 3.31$$

Likewise, the surplus corresponding to that case is found from combining 3.21, 3.28, 3.29 and 3.30 as

$$A - U = (1 - \rho_{ini})\, A_{crit,\infty} - U_{0,\infty} = (1 - \rho_{ini} - q_1\zeta)\, A_{crit,\infty} - q_2 d \qquad 3.32$$

where $A_{crit,\infty}$ must be substituted from Eq 3.30.
This surplus can still be negative at $A=A_{crit}$ in the pseudo equilibrium state; but it must be reminded that only effective N was taken as input in the definition used here for N surplus.

With the help of the above, we can now quantify pairs of $A_{crit,\infty}$ and $U_{0,\infty}$ that are consistent in a steady state situation. We take grass as an example and use the mean values of $\rho_{ini}$, $\alpha_{crit}$, $\gamma$ and $Y_{max}$ reported by ten Berge *et al.* (2000), $q_1 = q_2 = 0.8$, and a value of 0.5 for *w*. Taking $A_{crit}$ as the threshold rate that is still safe with respect to $N_{min,H}$, it follows that this dose ranges between 200 and 225 kg effective N per ha if all N were given as cattle slurry, (the lower value referring to $r = 1$ and the higher to $r = 0$). This is equivalent with 400-450 kg total N in slurry. If 50% of the effective N dose is given as fertiliser-N and 50% as effective slurry-N, the permissible dose would be 240-280 kg effective N per ha. This is equivalent with the same amounts in total slurry N ($w$=0.5 offsets the fact that half the dose is given as fertiliser). If all N is applied in mineral fertiliser, the doses are between 300 and 360 kg N/ha. The corresponding $U_{0,\infty}$ -values are 150 ($r = 0$) to 170 ($r = 1$) kg N per ha for the case with 100% slurry-N; 105 to 135 kg N per ha for 50% fertiliser-N and 50% slurry-N; and 40-90 kg N per ha if all N is given as mineral fertiliser.
Note that no assumptions on the value of the coefficient $\tau$ are required to estimate the equilibrium values $A_{crit,\infty}$ and $U_{0,\infty}$. The time coefficient does affect, however, the rate at which the steady state is approached, and the final size of the organic soil N pool, as noted already by Von Wulffen.

# 4. Accumulation of residual mineral nitrogen in grassland under cutting regime

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## 4.1 Introduction

In this chapter we present a series of multiple regression models for $N_{min,H}$, developed on the basis of data sets on cut grass experiments. The models differ from those presented in Chapter 3, in adopting a larger number of regressors and in ignoring the balance concept adhered to in that earlier chapter.

## 4.2 Origin of data sets

The data used in this chapter were mostly collected to investigate the recovery of applied N. Excess inorganic nitrogen was often measured in these experiments to allow the identification of the optimum amount of nitrogen to be applied on grassland (Prins, 1983).

Table 4.1 compiles general information on the experiments. Four soil types were included: sand, clay, well drained peat and poorly drained peat soils. Fertilisation was through mineral fertilisers, slurry or a combination of both.

The amount of mineral nitrogen retained in the soil profile by autumn was usually measured down to a depth of 1.0 m. Where profiles were sampled to shallower depth only, nitrogen in the remaining depth to 1.0 m was estimated at half the amount, per 10 cm depth interval, found in the deepest layer sampled (e.g., 60-90 cm or 50-75 cm).

## 4.3 Modelling approach

The statistical analyses were performed using the 'REML-procedure' (Genstat, release 4.1), because the data set consisted of data from several experiments and several years. Because of the log normality of the data, it was necessary to fit the response variate on log scale. The consequence was a multiplicative model, allowing to predict the variance components. The variance components were calculated for year, experiment and for experiment-by-year interactions. Factors associated with variations in $N_{min\,H}$ could be identified.
Each original experiment was conducted at one corresponding location. Only the SANS experiment included different soil types. In this experiment different codes were chosen to identify the different soil types. Effects due to the factor 'experiment' can be interpreted as location effects.

*Table 4.1. Overview of the experiments used for the statistical analyses of the estimation of residual inorganic nitrogen in the soil of grassland.*

| Number | Experiment | Years | Soil | Range of N fertilisation | Depth of sampling | No. N uptake | No. $N_{min,H}$ | No. $N_{min,S}$ | Type of Fertiliser [1)] | Source | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Bree | 1997 | Sand | 0-466 | 90 | 15 | | 15 | C,F,S,FS | | |
| 2 | CABO314 | 1997-1982 | Clay | 0-1059 | 100 | 16 | 16 | 16 | C,F | Unpublished data | |
| 3 | Droe | 1987-1990 | Sand | 0-611 | 100 | 32 | | 32 | C,F,S,FS | | |
| 4 | Geel | 1997 | Sand | 0-510 | 90 | 15 | | 15 | C,F,S,FS | | |
| 5 | IB2146 | 1974-1978 | Sand | 0-960 | 100 | 13 | 13 | 13 | C,F | Prins, 1983 | |
| 6 | IB2244 | 1975-1978 | Clay | 0-960 | 100 | 11 | 11 | 11 | C,F | Prins, 1983 | |
| 7 | IB2259 | 1975-1978 | Clay | 0-960 | 100 | 19 | 14 | 19 | C,F | Prins, 1983 | |
| 8 | IB3079 | 1986 | Clay | 0-560 | 100 | 5 | 5 | 5 | C,F | Prins & Postmus, 1987 | |
| 9 | IB3182 | 1988 | Sand | 0-560 | 100 | 5 | 5 | 5 | C,F | Oenema & Postmus, 1988 | |
| 10 | IB3184 | 1988 | Clay | 0-560 | 100 | 5 | 5 | 5 | C,F | Oenema & Postmus, 1988 | |
| 11 | IB3230 | 1989-1991 | Sand | 0-560 | 100 | 33 | 15 | 12 | C,F | Oenema & Postmus, 1989-1992 | |
| 12 | Lelystad | 1990-1991 | Clay | 0-480 | 100 | 20 | | 20 | C,F,S | Schils *et al.* (1999) | $N_{min,H}$ after 4th cut |
| 13 | Merelbeke | 1996-1998 | Sand | 0-509 | 90 | 45 | | 45 | C,F,S,FS | | |
| 14 | PR1556 | 1991-1994 | Sand | 160-420 | 75 | | 12 | 12 | F | Holshof | |
| 15 | PR3608 | 1995-1998 | Sand | 0-617 | 90 | | 21 | 11 | C,F | Wouters, 2001 | |
| 16 | PR49N | 1982-1984 | Sand | 0-600 | 100 | 12 | 12 | 12 | C,F | Wouters *et al.* (1995) | |
| 17 | PR49R | 1982-1984 | Sand | 0-660 | 100 | 12 | 12 | 12 | C,F | Wouters *et al.* (1995) | |
| 18 | Ruurlo | 1980-1984 | Sand | 0-889 | 100 | 159 | 160 | 40 | C,F,S,FS | Snijders *et al.* (1987) | |
| 19 | SANS_KA | 1992-1994 | Clay | 0-680 | 100 | 25 | 21 | 21 | C,F | Hofstede *et al.* (1995) | |
| 20 | SANS_KB | 1992-1994 | Clay | 0-437 | 100 | 8 | 7 | 8 | C,F | Hofstede (1995a,b) | |
| 21 | SANS_VDA | 1992-1994 | Peat dry | 0-529 | 100 | 25 | 22 | 22 | C,F | Hofstede *et al.* (1995) | |
| 22 | SANS_VDB | 1992-1994 | Peat dry | 0-336 | 100 | 7 | 7 | 8 | C,F | Hofstede (1995a,b) | |
| 23 | SANS_VNA | 1992-1994 | Peat wet | 0-700 | 100 | 25 | 22 | 22 | C,F | Hofstede *et al.* (1995) | |
| 24 | SANS_VNB | 1992-1994 | Peat wet | 0-464 | 100 | 7 | 7 | 8 | C,F | Hofstede (1995a,b) | |
| 25 | SANS_ZA | 1992-1994 | Sand | 0-683 | 100 | 22 | 22 | 22 | C,F | Hofstede *et al.* (1995) | |
| 26 | SANS_ZB | 1992-1994 | Sand | 0-464 | 100 | 7 | 8 | 8 | C,F | Hofstede (1995a,b) | |
| 27 | Tienen | 1996-1998 | Sand | 0-494 | 90 | 45 | 45 | | C,F,S,FS | | |
| 28 | Ureterp | 1990-1991 | Sand | 0-480 | 100 | 20 | 20 | | C,F,S | Schils *et al.* (1999) | $N_{min,H}$ after 4th cut |

[1)] *C: control; F: fertiliser; S: slurry; FS: combination of fertiliser and slurry*

## 4.4 Statistical model based on singular regressor variates

With no regard for the 'physical logic', we simply tried to identify the combination of regressors that best explained the variation in $N_{min,H}$. Examples of regressors are N dose, N uptake, the amount of rainfall in the growing season, and Spring time mineral soil nitrogen, $N_{min,S}$. The interpretation of regression coefficients in this type of models can be difficult, however, due to correlated regressors. For example, there is a very strong correlation between the applied N dose and the N uptake.

Observations of N uptake and, more often, $N_{min,S}$ were lacking in a number of experiments. Adopting those x-variates in the model meant we had to reduce the number of records in the data set. Three models were formulated:

Model 1a soiltype, fertiliser, N application
Model 2a soiltype, fertiliser, N application, N uptake
Model 3a soiltype, fertiliser, N application, N uptake, Rainfall, $N_{min,S}$

The three models were compared on the basis of the reduced data set. The size of this data set was 258 records. The complete set included 606 records. Table 4.2 shows the experiments contained in the reduced set.

The factor 'fertiliser' was introduced to identify possible effects of fertiliser type (mineral fertiliser, animal manure, combination, or zero input). In the final dataset, only experiments with chemical fertiliser remained, including with zero-N treatments. The factor 'fertiliser' therefore refers, in fact, to the presence or absence of N input. It was nevertheless retained in the model because it apparently improved the model performance.

*Table 4.2. Scheme of experiments used for the statistical analyses of the final model of residual inorganic nitrogen in the soil of grassland (smallest data set).*

| Number | Experiment | Years | Soil | Range of N fertilization | Depth of sampling | No. N uptake | No. $N_{min,H}$ | No. $N_{min,S}$ | Type of fertiliser | Source | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | CABO314 | 1997-1982 | Clay | 0-1059 | 100 | 16 | 16 | 16 | B,F | Unpublished data | |
| 5 | IB2146 | 1974-1978 | Sand | 0-960 | 100 | 13 | 13 | 13 | B,F | Prins, 1983 | |
| 6 | IB2244 | 1975-1978 | Clay | 0-960 | 100 | 11 | 11 | 11 | B,F | Prins, 1983 | |
| 7 | IB2259 | 1975-1978 | Clay | 0-960 | 100 | 19 | 14 | 19 | B,F | Prins, 1983 | |
| 8 | IB3079 | 1986 | Clay | 0-560 | 100 | 5 | 5 | 5 | B,F | Prins & Postmus, 1987 | |
| 9 | IB3182 | 1988 | Sand | 0-560 | 100 | 5 | 5 | 5 | B,F | Oenema & Postmus, 1988 | |
| 10 | IB3184 | 1988 | Clay | 0-560 | 100 | 5 | 5 | 5 | B,F | Oenema & Postmus, 1988 | |
| 11 | IB3230 | 1989-1991 | Sand | 0-560 | 100 | 12 | 12 | 12 | B,F | Oenema & Postmus, 1989-1992 | |
| 16 | PR49N | 1982-1984 | Sand | 0-600 | 100 | 12 | 12 | 12 | B,F | Wouters *et al.* (1995) | |
| 17 | PR49R | 1982-1984 | Sand | 0-660 | 100 | 12 | 12 | 12 | B,F | Wouters *et al.* (1995) | |
| 18 | Ruurlo | 1980-1984 | Sand | 0-889 | 100 | 40 | 40 | 40 | B,F,S,FS | Snijders *et al.* (1987) | |
| 19 | SANS_KA | 1992-1994 | Clay | 0-680 | 100 | 25 | 21 | 21 | B,F | Hofstede *et al.* (1995) | |
| 20 | SANS_KB | 1992-1994 | Clay | 0-437 | 100 | 8 | 7 | 8 | B,F | Hofstede (1995a,b) | |
| 21 | SANS_VDA | 1992-1994 | Peat | 0-529 | 100 | 25 | 22 | 22 | B,F | Hofstede *et al.* (1995) | |
| 22 | SANS_VDB | 1992-1994 | Peat | 0-336 | 100 | 7 | 7 | 8 | B,F | Hofstede (1995a,b) | |
| 23 | SANS_VNA | 1992-1994 | Peat | 0-700 | 100 | 25 | 22 | 22 | B,F | Hofstede *et al.* (1995) | |
| 24 | SANS_VNB | 1992-1994 | Peat | 0-464 | 100 | 7 | 7 | 8 | B,F | Hofstede (1995a,b) | |
| 25 | SANS_ZA | 1992-1994 | Sand | 0-683 | 100 | 22 | 22 | 22 | B,F | Hofstede *et al.* (1995) | |
| 26 | SANS_ZB | 1992-1994 | Sand | 0-464 | 100 | 7 | 8 | 8 | B,F | Hofstede (1995a,b) | |

Figure 4.1 shows all observations contained in the complete data set, arranged per soil type. The fitted Model 1a is given as well. Only soil type and N application are the regressors in this model. Figure 4.2 shows the data per separate experiment, along with the best fitting curve based on Model 1a.

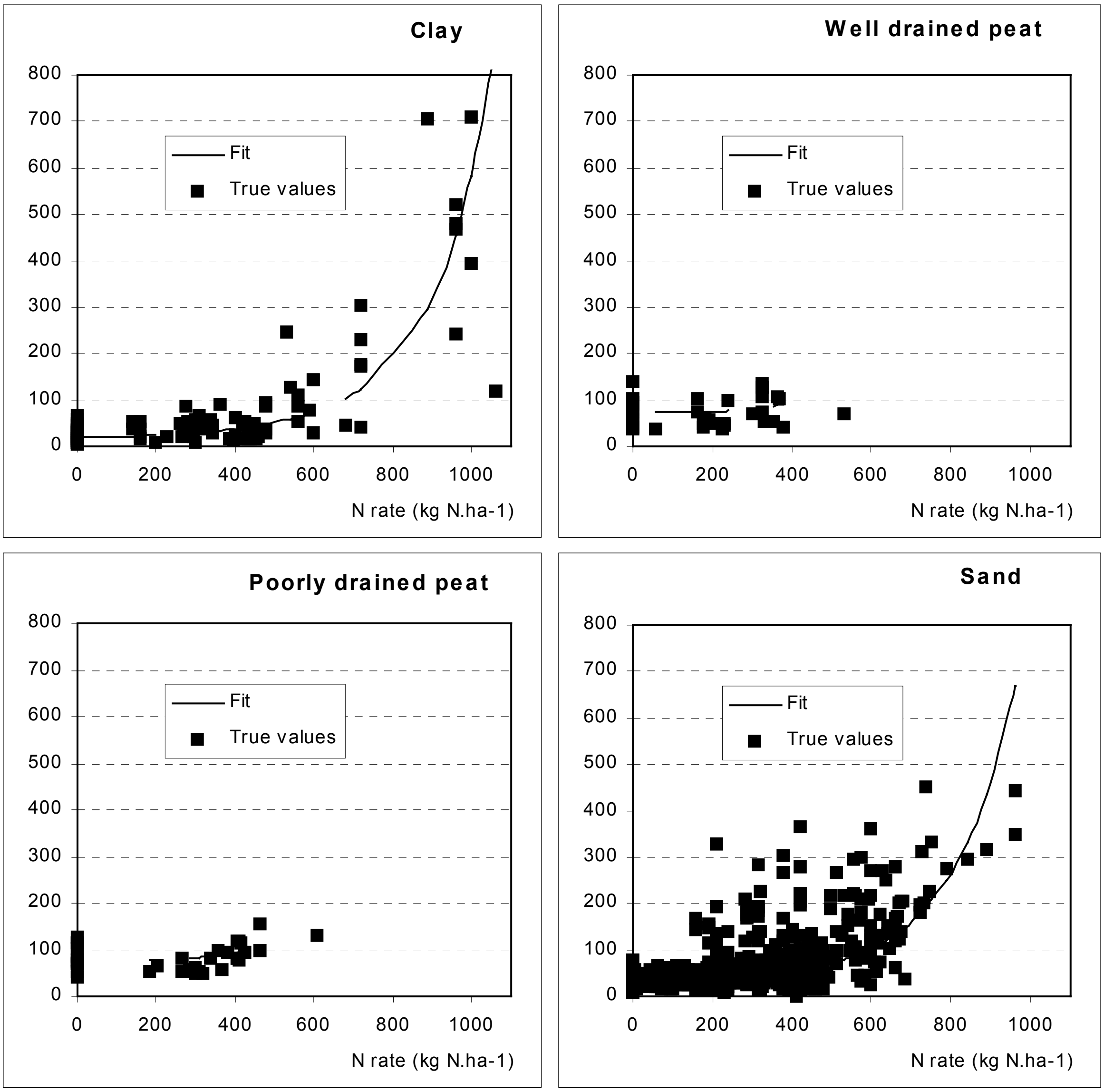


*Figure 4.1.* *Observed $N_{min,H}$ in the complete data set, grouped by soil type; the curves represent the fit by the simplest model (Model 1a).*

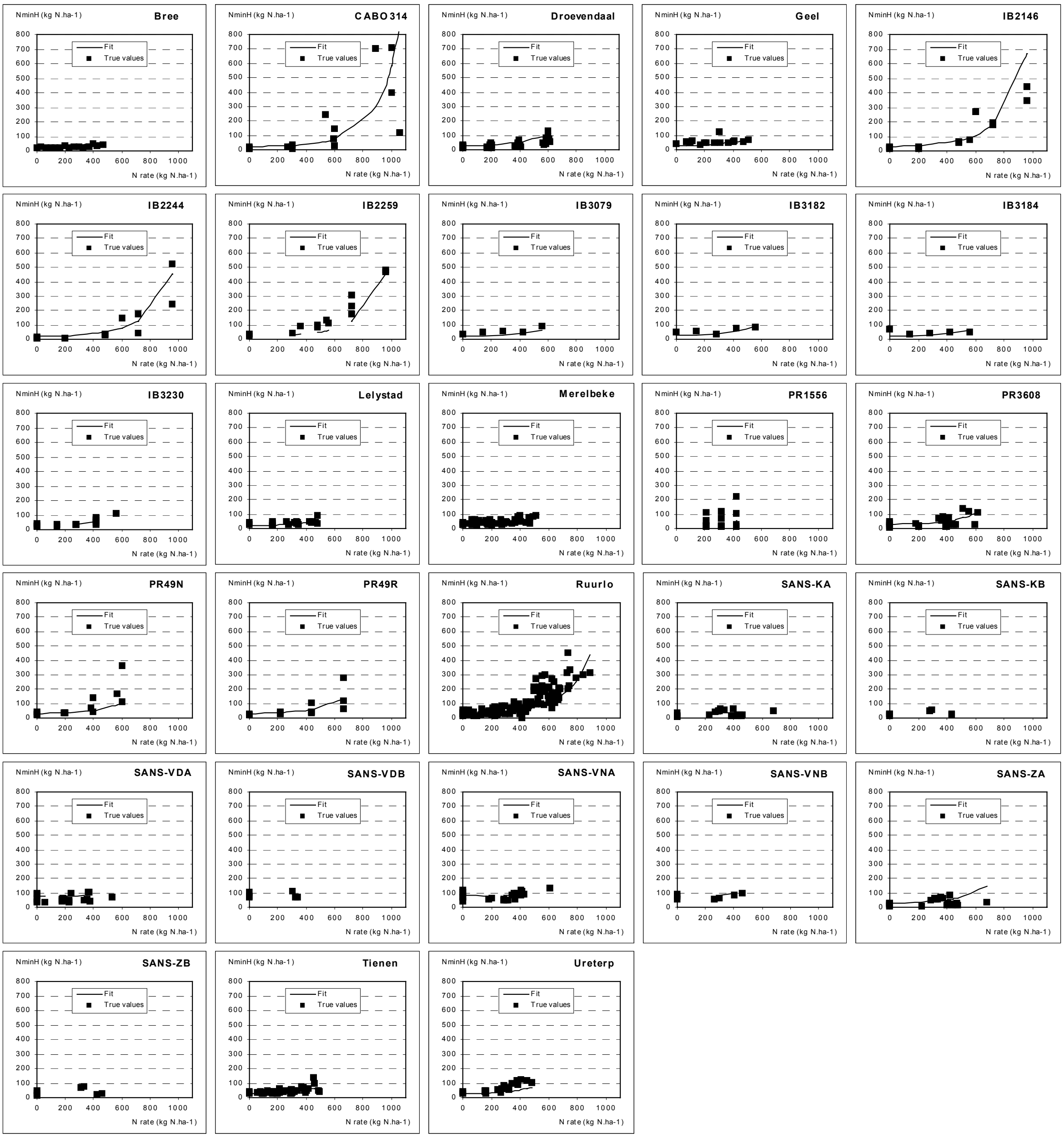


*Figure 4.2.* *Observed $N_{min,H}$ values in the complete data set presented per experiment, with the best fitting curve of the simple Model 1a.*

Table 4.3 shows the expected values of $N_{min,H}$ based on Model 1a for a series of common N application levels.

*Table 4.3. N application related to $N_{min,H}$ calculated for a range of N application levels (Based on Model 1a of this chapter).*

| Soil type | N application (kg N.ha-1) | | | | |
|---|---|---|---|---|---|
| | 150 | 250 | 350 | 450 | 550 |
| Clay | 22 | 26 | 33 | 44 | 61 |
| Peat dry | 74 | 79 | 89 | 107 | 136 |
| Peat wet | 76 | 79 | 87 | 101 | 125 |
| Sand | 30 | 36 | 45 | 61 | 87 |

Table 4.4 shows the most relevant models evaluated. Note that the basic model (Model 1a) was fitted to the the complete data set and that the statistics refer to that set. There was only a minor difference between the results (parameter predictions and model performance) obtained for the complete and for the reduced data set (Model 2a – N uptake). Remarkable is the high variance component experiment-by-year in the complete data set ($S^2 = 0.1989$).

*Table 4.4 Statistics for three fixed models: number of observations (N), degrees of freedom (dof), estimated variance components, and the percentage of total variance accounted for ($R^2$), for the random model, the maximum model and the final model.*

| Model | N | dof | $s^2$ year | $s^2$ experiment | $s^2$ experiment year | $s^2$ residual | $s^2$ total | $R^2$ total |
|---|---|---|---|---|---|---|---|---|
| 3a X-variables: soil, rainfall, N application, $N_{min,S}$ (reduced data set) | | | | | | | | |
| Random model | 258 | 254 | 0.0039 | 0.0921 | 0.0643 | 0.6161 | 0.7764 | 0 |
| Maximum model | 258 | 234 | 0.0519 | 0.0144 | 0.05814 | 0.09377 | 0.2183 | 0.718882 |
| Final model (F3a) | 258 | 239 | 0.0515 | 0.0311 | 0.04376 | 0.09706 | 0.2234 | 0.712262 |
| F3a + N uptake | 258 | 238 | 0.0432 | 0.023 | 0.0478 | 0.9786 | 0.2118 | 0.727202 |
| F3a - Rainfall | 258 | 245 | 0.0035 | 0.003 | 0.1371 | 0.1091 | 0.2529 | 0.674266 |
| F3a - $N_{min,S}$ | 258 | 241 | 0.078 | 0.043 | 0.0545 | 0.105 | 0.2805 | 0.638717 |
| 2a X-variables: soil, N application, N uptake (reduced data set) | | | | | | | | |
| N application, soil and N uptake | 258 | 245 | 0.0315 | 0.012 | 0.164 | 0.1224 | 0.3302 | 0.574704 |
| - N uptake | 258 | 246 | 0.0307 | 0.012 | 0.1638 | 0.1219 | 0.3287 | 0.576636 |
| 1a X-variables: soil, N application (full data set) | | | | | | | | |
| Random model | 606 | 602 | 0.0166 | 0.063 | 0.1112 | 0.446 | 0.6366 | 0 |
| N application and soil | 606 | 594 | 0.0431 | 0 | 0.1989 | 0.1017 | 0.3437 | 0.460101 |

*1) Model including all terms and interactions*

### 4.4.1 Final model (3a) based on singular variates

It appears (Table 4.4) that about 70 percent of all the variance in $N_{min,H}$ can be explained, when the model not only includes soil type and N application, but also the remaining available regressors:

Rainfall and $N_{min,S}$. $N_{min,S}$ explains a significant part of the variance: leaving out this variate reduces $R^2$ to about 0.63. Less impact had the regressor N uptake; its contribution was not significant and it was ignored as regressor in the final model. The percentage of variance explained drops by 2 to 3 percent points when Rainfall is omitted from the model.

The Model 3a was finally defined as:

$$\text{Log}(\underline{Y}_{ijkl}) = \beta_{0i} + (\beta_{11} + \delta_i)X_1 + (\beta_{21} + \gamma_i)X_2 + \beta_3 X_3 + \beta_4 X_1^2 + \beta_5 X_1 X_2 + \beta_6 X_2 X_3 + \underline{\varepsilon}_j + \underline{\varepsilon}_k + \underline{\varepsilon}_{jk} + \underline{\varepsilon}_{ijkl} \quad 4.1$$

Discription of the parameters:

| | |
|---|---|
| $\underline{Y}_{ijkl}$ | $N_{min,H}$ of soil type $i$ , in year $j$ , location $k$ and experimental field number $l$ |
| $X_1$ | $A$ (applied effective N, kg/ha) |
| $X_2$ | cumulated rainfall during the growing season |
| $X_3$ | $N_{min,S}$ |
| $\beta_{0i}$ | intercept parameter of $N_{min,H}$ of soil type $i$ |
| $\beta_{11}$ | curve (by intercept parameter $\beta_{0i}$) in $N_{min,H}$ as a result of N application on clay soil (i=1) |
| $\delta_i$ | deviation in curve (with regard to $\beta_{11}$) for soil type peat dry (i=2), peat wet (i=3) and sand (i=4) |
| $\beta_{21}$ | curve (by intercept) in $N_{min,H}$ as a result of rainfall in combination of soil type clay (i=1) |
| $\gamma_i$ | deviation in curve (with regard to $\beta_{21}$) for soil type peat dry (i=2), peat wet (i=3) and sand (i=4) |
| $\beta_3$ | overall parameters for respective $N_{min,S}$ |
| $\beta_4$ | parameter for quadratic term of $A$ ($X_1$) |
| $\beta_5$, $\beta_6$ | parameters for interaction-terms $X_1X_2$en $X_2X_3$ |

$\underline{\varepsilon}_j \sim N(0,\sigma_j^2), \underline{\varepsilon}_k \sim N(0,\sigma_k^2), \underline{\varepsilon}_{jk} \sim N(0,\sigma_{jk}^2)$ respective random effects of years and experiments

$\underline{\varepsilon}_{ijkl}$ residual variance

Table 4.5 shows the parameter estimates for the Models 1a, 2a and 3a. For Model 1a, the results are given for both the complete and the reduced data set (is Model 2a, N uptake not included). The data selection has apparently a strong impact on some parameters.

For Model 3a, the estimates are given for cases with and without the inclusion of rainfall as regressor. All models describe $N_{min,H}$ reasonably well. Model 3a shows the highest $R^2$–value (Table 4.4).

*Table 4.5. Parameter estimates for Model 1a (complete data set and reduced data set), Model 2a, and Model 3a (with and without rainfall as regressor).*

| | Soil | $\beta_{0i}$ | $\beta_{11}$ | $\delta_i$ | $\beta_{21}$ | $\gamma_i$ | $\beta_3$ [1)] | $\beta_4$ | $\beta_5$ | $\beta_6$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **Model 1a** | | | | | | | | | | |
| complete data set | | | | | | | | | | |
| estimates | Clay | 2.982 | 0.0004266 | 0 | | | | 0.00000296 | | |
| | Peat dry | 4.3189 | 0.0004266 | -0.0009697 | | | | 0.00000296 | | |
| | Peat wet | 4.3854 | 0.0004266 | -0.0012434 | | | | 0.00000296 | | |
| | Sand | 3.2452 | 0.0004266 | 0.0001666 | | | | 0.00000296 | | |
| se | | 0.05757 | 0.0002333 | 0.0003813 | | | | 0.000000237 | | |
| **Model 2a, *N* uptake not included (= Model 1a, reduced data set)** | | | | | | | | | | |
| reduced data set | | | | | | | | | | |
| estimates | Clay | 2.908 | 0.0007876 | 0 | | | | 0.000002602 | | |
| | Peat dry | 4.2538 | 0.0007876 | -0.0012848 | | | | 0.000002602 | | |
| | Peat wet | 4.3196 | 0.0007876 | -0.0014356 | | | | 0.000002602 | | |
| | Sand | 3.2155 | 0.0007876 | 0.0000593 | | | | 0.000002602 | | |
| se | | 0.06387 | 0.0003107 | 2.12E-07 | | | | 0.000000324 | | |
| **Model 3a** | | | | | | | | | | |
| Rainfall not included | | | | | | | | | | |
| estimates | Clay | 2.652 | 0.0007675 | 0 | | | 0.005406 | 0.000001681 | | |
| | Peat dry | 3.8398 | 0.0007675 | -0.0006879 | | | 0.005406 | 0.000002422 | | |
| | Peat wet | 3.999 | 0.0007675 | -0.001038 | | | 0.005406 | 0.000002422 | | |
| | Sand | 3.0124 | 0.0007675 | 0.0004533 | | | 0.005406 | 0.000002422 | | |
| se | | 0.1203 | 0.0002935 | 1.93E-07 | | | 0.000832 | 0.000000446 | | |
| Final model, rainfall included | | | | | | | | | | |
| estimates | Clay | 3.62 | 0.003133 | 0 | -0.00207 | 0 | -0.00321 | 0.000001652 | -0.000005016 | 0.00001876 |
| | Peat dry | 1.921 | 0.003133 | -0.0001607 | -0.00207 | 0.005542 | -0.00321 | 0.000001652 | -0.000005016 | 0.00001876 |
| | Peat wet | 1.688 | 0.003133 | -0.0005635 | -0.00207 | 0.006196 | -0.00321 | 0.000001652 | -0.000005016 | 0.00001876 |
| | Sand | 3.22 | 0.003133 | 0.0003912 | -0.00207 | 0.001567 | -0.00321 | 0.000001652 | -0.000005016 | 0.00001876 |
| se | | 0.4803 | 0.0005396 | 1.81E-07 | 0.001052 | 0.001208 | 0.003099 | 0.00000032 | 0.000000993 | 0.00001876 |

[1)] *In model 3a without rainfall as regressor, $\beta_3$ is an estimate for the interaction of $N_{min,S}$ and soil type*

Figure 4.3 shows the curves by Model 3a, plotted versus the applied N dose. To allow for one-dimensional graphs, the x variate rainfall was fixed at two values (400 and 500 mm) and $N_{min,S}$ was fixed at 50 kg N ha-1.

The amount of rainfall till harvest affected $N_{min,H}$, in all four soil types, but the effect depended on N dose, and the direction of the effect differed between soil types. $N_{min,H}$ decreased considerably on the two peat soils if precipitation was lowered; while $N_{min,H}$ on the sand and clay soils increased under lower precipitation. Only the peat soils showed a great difference in $N_{min,H}$ due to rainfall in the zero-N plots. In addition the curves of the well drained peat soil had a consistently higher level than the curves of the poorly drained peat soil. It is stressed that this unexpected positive effect of rainfall on peat soils was based on limited data.

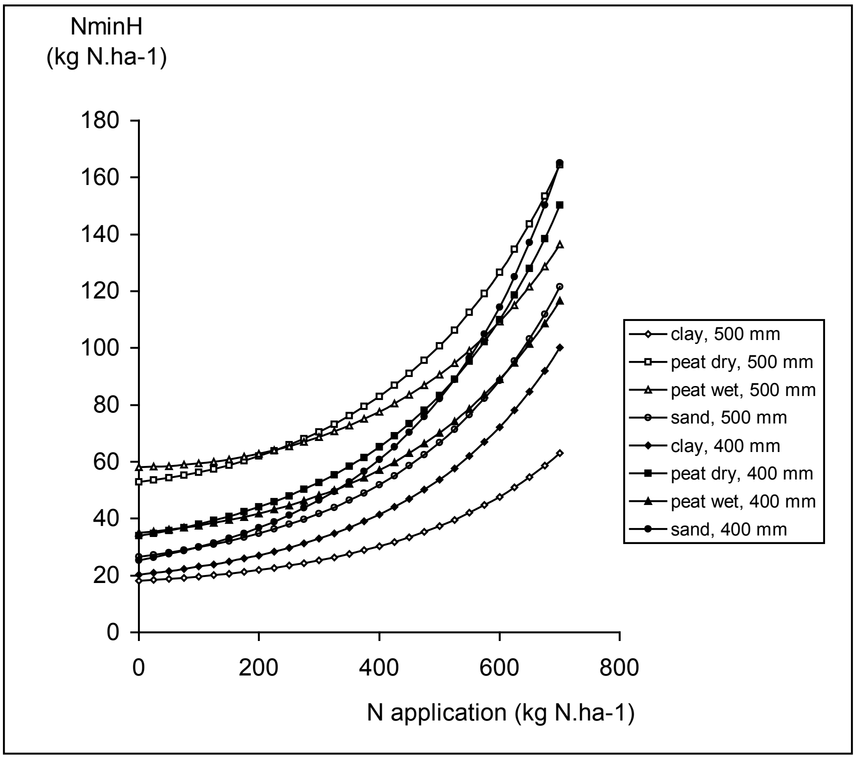


*Figure 4.3.* *Effect of rate of N application on change in mineral nitrogen in the 0-100 cm soil layer at harvest, on four soil types.* $N_{min,S}$ *is fixed on 50 kg N ha*$^{-1}$ *and the rainfall in the growing season on either 400 or 500 mm.*

### 4.4.2 Prediction intervals

Model 3a was used to predict the value of $N_{min,H}$ (in the 0-100 cm soil layer at harvest) for new fields and future years, in function of the N dose. The uncertainty of predictions for new fields is expressed in 'prediction intervals'. The prediction of log($N_{min,H}$) for future observations on a field of soiltype $i$ is:

$$\Pr ed(Log(N_{\min H})) = \hat{\beta}_{0i} + (\hat{\beta}_{11} + \hat{\delta}_i)X_1 + (\hat{\beta}_{21} + \hat{\gamma}_i)X_2 + \hat{\beta}_3 X_3 + \beta_4 X_1^{\,2} + \hat{\beta}_5 X_1 X_2 + \hat{\beta}_6 X_2 X_3 \qquad 4.2$$

where greek letters with a hat denote the estimates of the corresponding regression parameter. The uncertainty in a prediction for a new fields comes from two sources: uncertainty in the regression parameter estimates and uncertainty due to random effects of fluctuations between years, locations (experiments), interaction between years and location and residual effects. Under the assumption that random and residual effects are uncorrelated the variance of the prediction of new observations is written as

$$\mathrm{var}(pred(\log(N_{\min H})_{newobservation}) = \mathrm{var}(prediction) + \sigma^2{}_{year} + \sigma^2{}_{location} + \sigma^2{}_{year.location} + \sigma^2{}_{residual} \quad 4.3$$

Prediction intervals are constructed in two steps. In step 1 a 90 percent prediction interval, based on a normal approximation, is calculated for log ($N_{min,H}$), i.e.

$$Pred\,interval = (Pred(Log(N_{\min H})) - 1.65\sqrt{\mathrm{var}(pred)}, Pred(Log(N_{\min H})) + 1.65\sqrt{\mathrm{var}(pred)}) \quad 4.4$$

In step 2 a prediction interval is constructed for $N_{min,H}$ by backtransformation of the limits of the interval for log($N_{min,H}$).

To allow a one-dimensional view of the relationship between applied N dose, expected $N_{min,H}$ and prediction intervals for new cases, predictions and 90 percent prediction intervals of $N_{min,H}$ were calculated with rainfall fixed at 400 and 500 mm respectively and $N_{min,S}$ fixed at 50 kg ha$^{-1}$.

It turns out (Figures 4.4 and 4.5) that the uncertainty in $N_{min,H}$ predictions for future (new) cases (years, fields) is very high. This confirms similar results (Chapter 3) based on another modelling approach. It seems that the uncertainty based on the current model is larger than the uncertainty associated with the models in Chapter 3, but that is largely attributable to differences between the respective data sets. With exactly identical data sets, the uncertainty levels are virtually the same when evaluated at the same values of rainfall (not documented here).

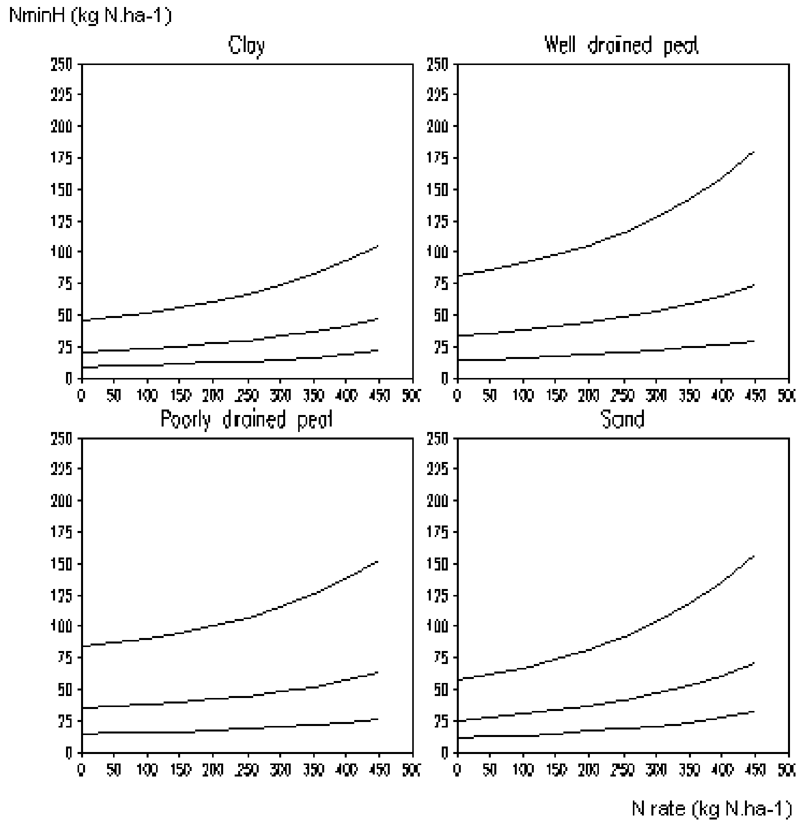


*Figure 4.4. Prediction and bands of 90 percent prediction interval for $N_{min,H}$ on 'new fields'. Results based on Model 3a with $N_{min,S}$ =50 kg N ha$^{-1}$ and rainfall of 400 mm in growing season.*

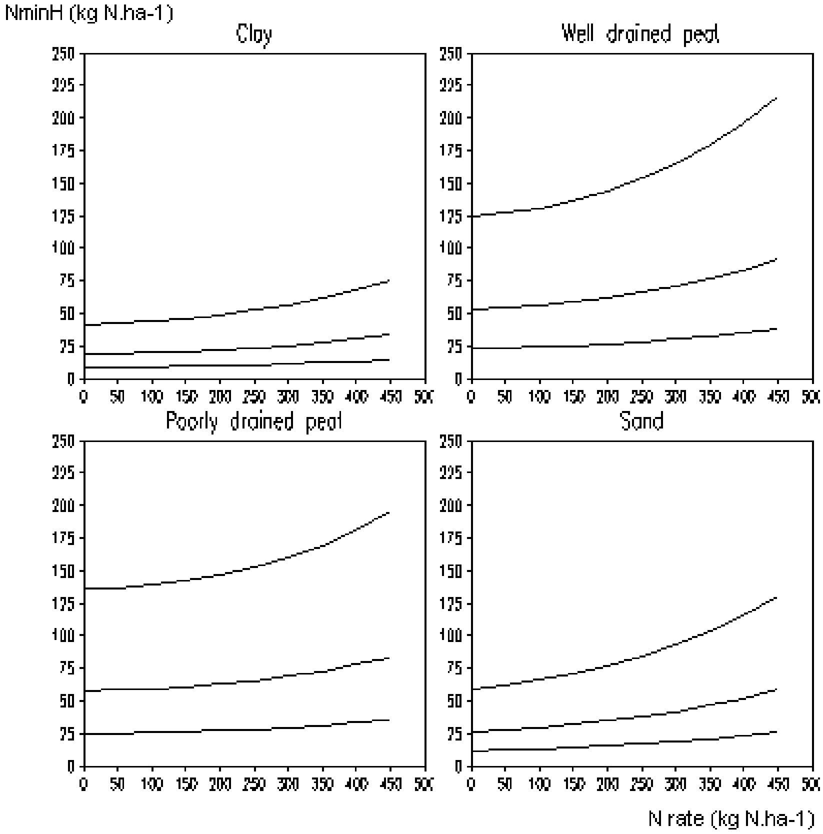


*Figure 4.5.* *Prediction and bands of 90 percent prediction interval for $N_{min,H}$ on new fields. Results based on model 3a with $N_{min,S}$ =50 kg N $ha^{-1}$ and rainfall of 500 mm in growing season.*

## 4.5 Statistical model based on compound regressor variates

In the analysis described in the previous paragraph only singular variates were used. In this paragraph we investigate the possibility that compound regressors might have a direct relationship with the amount of $N_{min,H}$. Such models have obviously the limitation that a single regression coefficient is associated with several 'independents', which are now forced into a single regressor. The following models were compared:

Model 1a soil, fertiliser, N application
Model 2b soil, fertiliser, (N application - N uptake)
Model 3b soil, fertiliser, Rainfall, (N application - N uptake + $N_{min,S}$)

See comments on the meaning of the factor 'fertiliser' in Paragraph 4.4. In Table 4.6 the results are shown of the models based on compound x –variates.

*Table 4.6. Scheme of the three fixed models and submodels with the number of observations (N), degrees of freedom (dof), estimated variance components, and the percentage of total variance accounted for models ($R^2$).*

| Model | N | dof | $s^2$ year | $s^2$ experiment | $s^2$ experiment year | $s^2$ residual | $s^2$ total | $R^2$ total |
|---|---|---|---|---|---|---|---|---|
| 3b Soil, fertiliser, Rainfall, (N application - N uptake + $N_{min,S}$). Comparable with model 3a without rainfall | | | | | | | | |
| Final model (F3b) | 258 | 245 | 0.0332 | 0.049 | 0.1685 | 0.1262 | 0.3769 | 0.514554 |
| F3b- fertiliser | 258 | 247 | 0.0425 | 0.0601 | 0.18787 | 0.1281 | 0.4186 | 0.460884 |
| 2b Soil, fertiliser, (N application - N uptake). Comparable with final model 2a | | | | | | | | |
| Final model (F2b) | 258 | 245 | 0.0633 | 0.067 | 0.2818 | 0.14 | 0.5521 | 0.288897 |
| F2b- fertiliser | 258 | 246 | 0.767 | 0.0706 | 0.3002 | 0.1381 | 0.5856 | 0.24575 |
| 1a Soil, fertiliser, N application | | | | | | | | |
| Final model | 606 | 594 | 0.0431 | 0 | 0.1989 | 0.1017 | 0.3437 | 0.460101 |

We might expect that $N_{min,H}$ is stronger related to the part of N application that has not been taken up by the grass than to the N application itself. The unused N application is the N application minus N uptake and is therefore a compound x-variate. Comparison between Tabels 4.4 and 4.6 shows that the compound variate selected here (N-dose minus N-uptake) is a poor basis for predicting $N_{min,H}$. The reasons are explained in Chapter 3: uptake is largely affected by soil-supplied N, and not all applied nitrogen that is not taken up remains as mineral N in the soil profile. We conclude that the use of compound regressors may be attractive only when they introduce additional information into the model, e.g., when they incorporate a (non-linear) model in themselves (as in Chapter 3).

## 4.6 Statistical model based on compound response variates

In this study, compound response variates have been evaluated for their ability to predict the effect of N application on $N_{min,H}$. The effect of N application could be modelled in a more direct way by subtracting the amount of mineral N in unfertilised plots, $N_{min,H,0}$, from $N_{min,H}$. This way of modelling also has a serious limitation as the total variance has to be taken into account. The total variance can be at least the sum of the variance of both response variates. It is only when the error in measurement is relatively small that such a model can be successful. By modelling $N_{min,H}$.an improvement is not expected.

As with compound x-variates the same theoretical view of the physical process could lead to a preference for a compound y-variate instead of using singular respons variates. For example, in this study we may expect the difference between $N_{min,H}$.and $N_{min,S}$. to be related to the level of N application in the intermediate period. The surplus value of this way of modelling is strongly dependent on the measurement errors of those respons variates. The measurement error of $N_{min}$ is not precisely known, but the residual variance gives us an indication. The variance coefficient was approximately 30 - 40 percent.
The measurement error of a compound y variate is twice as large, namely var (y1-y2) = var y1+var y2 (+ covariance). The variance of the compound response variate is therefore much higher. Table 4.7 shows the results for those models. $s^2$ total is much larger than those of the equivalent models in Table 4.4.

*Table 4.7. Scheme of three fixed models including submodels with the number of observations (N), degrees of freedom (dof), estimated variance components, and the percentage of total variance accounted for ($R^2$).*

| Model | N | dof | $s^2$ year | $s^2$ experiment | $s^2$ experiment year | $s^2$ residual | $s^2$ total | $R^2$ total |
|---|---|---|---|---|---|---|---|---|
| 4a Compound respons variates ($N_{min,H}$ - $N_{min,H,0}$) | | | | | | | | |
| Randommodel | 3764 | 372 | 0.186 | 0.152 | 0.038 | 1.443 | 1.8190 | |
| + $A$ | 376 | 371 | 0.2257 | 0.0001 | 0.2431 | 0.5712 | 1.0401 | 0.428202 |
| + soil and fertiliser | 376 | 364 | 0.2582 | 0.0001 | 0.2327 | 0.5554 | 1.0464 | 0.424739 |
| 5a Compound respons variates ($N_{min,H}$ - $N_{min,H,0}$) and regressor ($U - U_0$) | | | | | | | | |
| + $A$ | 376 | 371 | 0.2257 | 0.0001 | 0.2431 | 0.5712 | 1.0401 | 0.428202 |
| + ($U - U_0$) | 376 | 370 | 0.2189 | 0.0027 | 0.2306 | 0.5654 | 1.0176 | 0.440572 |
| + soil and fertiliser | 376 | 358 | 0.2282 | 0.0001 | 0.2442 | 0.5519 | 1.0244 | 0.436833 |
| 5b Compound respons variates ($N_{min,H}$ - $N_{min,H,0}$) and regressor $A$ + ($U - U_0$) | | | | | | | | |
| Randommodel | 376 | 372 | 0.186 | 0.152 | 0.038 | 1.443 | 1.8190 | |
| + $A$ + ($U - U_0$) | 376 | 371 | 0.2331 | 0.0358 | 0.1996 | 0.6718 | 1.1403 | 0.373117 |
| + soil and fertiliser | 376 | 365 | 0.2388 | 0.498 | 0.1724 | 0.6733 | 1.5825 | 0.130016 |

## 4.7 Model with information of the zero plots as variates

To answer the question what the effect is of not including the zero plots in the analyses and using this information as x-variates in the fixed models instead, a few other models were made. In this exercise, $N_{min,H}$ observations on zero-$N$ plots were excluded from the dataset, and the crop uptake $U_0$ on those plots was either excluded (Model 6a = Model 3a) or included as X-variate in the model (Model 6a = Model 3a + $U_0$). The results are shown in Table 4.8.

When comparing the percentage of total variance accounted for models ($R^2$) from Table 4.8 and from Table 4.4 it shows that the values in Table 4.8 are 10 percent points higher. The percentage of total variance accounted for these models is more than 80 percent. The change is due to the exclusion of observations in zero-N plots. This could indicate that $N_{min,H}$ in zero plots is hard to predict. Using the uptake information of zero plots in the model F3a + ($U_0$) gives a relatively small improvement in the total variance accounted for by model. It must be noted that the model in Table 4.8 is not suitable for application in the low-N range, because no data on zero-N plots were used in defining the model.

*Table 4.8. Scheme of the fixed models including submodels with the number of observations (N), degrees of freedom (dof), estimated variance components, and the percentage of total variance accounted for models ($R^2$).*

| | Model | N | dof | $s^2$ year | $s^2$ experiment | $s^2$ experiment year | $s^2$ residual | $s^2$ total | $R^2$ total |
|---|---|---|---|---|---|---|---|---|---|
| 6a | $U_0$ used as singular X-term, $N_{min,H}$ observations on zero-N plots excluded | | | | | | | | |
| | Random model | 191 | 187 | 0.035 | 0.0865 | 0.645 | 0.52 | 1.2865 | |
| | Final model 3a (F3a) | 191 | 172 | 0.10301 | 0.00869 | 0.04384 | 0.07309 | 0.2286 | 0.822285 |
| | F3a + ($U_0$) | 191 | 171 | 0.0758 | 0.00001 | 0.05568 | 0.07294 | 0.2044 | 0.841096 |
| | F3a - interactions (Rainfall * N application) and (Rainfall * $N_{min,S}$) | | | | | | | | |
| | | 191 | 173 | 0.06795 | 0.00001 | 0.06043 | 0.07539 | 0.2038 | 0.841601 |
| | F3a - interactions (N application * soil) | | | | | | | | |
| | | 191 | 176 | 0.07546 | 0.0001 | 0.05634 | 0.07926 | 0.2111 | 0.835935 |
| | F3a - quadratic term of N application | | | | | | | | |
| | | 191 | 177 | 0.07222 | 0.0001 | 0.05573 | 0.07954 | 0.2075 | 0.83871 |

## 4.8 Discussion

The chief purpose of the studies in this chapter was to assess models which accurately explain variation in $N_{min,H}$ based on combinations of available information, irrespective of model complexity or difficulties with interpreting the parameters. It appears that the data set, and therefore also the models, were insufficient for a clear determination of the behaviour of $N_{min,H}$ at very low rates of N application. In several sub models a decrease of $N_{min,H}$ occurred with increasing N application.

The amount of rainfall during the growing season had a strong effect on $N_{min,H}$, especially on peat soils, depending on the applied N rate. With less rain $N_{min,H}$ decreased considerably on both peat soils while it increased on sand and clay soils. The latter response could be explained from a decreased uptake under drier conditions on the mineral soil types. We can only guess that rainfall might hamper growth conditions, to explain the reversed pattern in peat soils.
The efficiency of harvesting grass or grazing decreases, too, on wetter peat soils. Anyhow, limited data were available as a basis for the contrasting responses and the above suggestions must be confirmed by additional data.

It appears that the variance components for years are higher than the variance components for locations / experiments. The interpretation is as follows:

- The variance component is more than 23% due to differences between years (0,0515/(0,0515+0,0311+0,0438+0,09706)
- About 14% (0,0311 / total variance) of the variance can be explained by differences between experiments (locations)
- 60 to 65 percent of the total variance can be explained by the variance within experiments (regardless of the year)

The terms in the fixed model are strongly correlated. The parameter estimates have to be judged in that view. The terms that showed the strongest correlation in the submodels are N application and N uptake. In general, high values of N application are accompanied by high values of N uptake. Because of this correlation N uptake did not improve the final model.

## 4.9 Conclusions

The conclusions for the final model (3a) are as follows:

- Despite the fairly high percentage of total variance accounted for ($R^2$), considerable uncertainty is associated with new predictions of $N_{min,H}$. For instance: at N-rates of 300 kg ha$^{-1}$ (sandy soil, rainfall 400 mm) the expected value is $N_{min,H}$ = 45 kg N.ha$^{-1}$, but 90% of the population may have a $N_{min,H}$ value between 20 and 100 kg N.ha$^{-1}$ (Figure 4.4.)
- The relation between N application and $N_{min,H}$ on log scale can be described by a quadratic curve. As the amount of N supply is increased, $N_{min,H}$ increases more than proportional. Responses at relatively low N supply are stronger on sandy soils than on poorly drained peat soils.
- Soil type causes differences in levels of $N_{min,H}$ (on peat soil $N_{min,H}$ is generally much higher). This is likely to be related to a difference in mineralisation of organic nitrogen, and the difference is independent of the fertiliser level
- The effect of rainfall on sand and clay soil is related to N application. $N_{min,H}$ on the 'zero-N plots' is not different on sand and clay and independent of the amount of rainfall. Less fertiliser N is recovered as $N_{min,H}$ after a wet growing season. Peat soil gives another result. A larger amount of rainfall on the 'zero-N plots' leads to an increase of $N_{min,H}$. The relative influence of rainfall increases as more N is supplied
- Including $N_{min,S}$ improves the model (variance accounted for)
- Including the uptake in zero-plots ($U_0$) as variate into the model gives some increase of the fraction of total variance accounted for, as compared to Model 3a, but a much larger improvement is obtained when $N_{min,H}$ observations on the zero-plots are excluded from the data set ($R^2$ increases by about 10 percent points).

# 5. Estimation of residual mineral soil nitrogen in arable crops and field vegetables at standard recommended N-rates

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## 5.1 Introduction

In this chapter the relationship is discussed between the effective N-rate and the amount of residual soil nitrogen (N) at the time of crop harvest ($N_{min,H}$), taking into account factors such as soil type, growing period of the crop and summer precipitation. Based on an extensive number of field experiments, the $N_{min,H}$ at recommended N-rates is predicted by means of linear and non-linear models. This information is used in chapter 9 for relating N-surplus at the field and farm level to $N_{min,H}$.

## 5.2 Origin of data sets

Data from relevant field experiments carried out from 1987 were collected for about 30 common arable crops and field vegetables grown in the Netherlands (Table 5.1). For maize, data originate even from 1987. Data sets used in this chapter include information on the amount of residual soil nitrogen (N) at the time of crop harvest ($N_{min,H}$) in the soil layer of 0-60 cm at known: effective N-rates, type of soil (sandy, retained peat, loess and clay), location and the date of planting and harvest. The $N_{min,H}$ –data from most loess experiments were determined in the layer of 0-90 cm. Spinach data refer only to 0-30 cm. To allow comparison between soils and crops, the $N_{min,H}$ 0-60 cm for loess and spinach have been estimated by multiplying the data with 0.66 and 2.0 respectively. Data of the sandy and retained peat soils have been merged since they have similar characteristics regarding the behaviour of nitrogen. In the following, sandy soils refer to both type of soils. The number of observations per crop differs substantially, depending on the attention paid to environmental aspects in recent research. For instance, the number of collected observations for maize, potato and sugar beet were 980, 461 and 322 respectively, while the number for most horticultural crops did not exceed 50.

Data were collected from field trials with fixed N-rates and from trials where different cropping systems were compared (as in farming systems research). For field trials with fixed N-rates, averages were taken per treatment (often consisting of 3 to 4 replications). The farming systems research trials did not have replications. Therefore every observation was used separately (consisting of a mixed sample from 16 tot 20 samples taken diagonally over the plot, depending on the size of the plot).

In many trials manure has been used. The effective N-rate was calculated as the sum of mineral N-fertiliser and the effective N-rate of the manure. The effective N-rate of the manure was determined by multiplying the total N-rate with 0.2 and 0.7 for application of manure in autumn and spring respectively (Van Dijk, 1999). The total N-rate is calculated from the applied rate and measured N-content of the manure.

For maize and potatoes the total precipitation between planting and harvest has been determined based on observations from meteorological stations in the vicinity of the trials.

*Table 1. Overview of the collected data for investigating the residual mineral soil nitrogen at harvest in arable crops and field vegetables.*

| Crop | Soil | No. of trials | No of obs. | Years | Source |
|---|---|---|---|---|---|
| cauliflower | clay | 4 | 48 | 90,92 | Everaarts, 1995 |
| broccoli | clay | 4 | 48 | 90-92 | Everaarts, 1995 |
| | sand | 5 | 14 | 91-95 | Kroonen-Backbier, 1999 |
| Chinese cabbage | sand | 5 | 13 | 91-95 | Kroonen-Backbier, 1999 |
| ware potatoes | clay | 15 | 166 | 87-98 | Hengsdijk, 1992; Titulaer, 1997, Van Loon, 1998; Anon., 1999 |
| | loess | 4 | 64 | 95-98 | Geelen 1999 |
| | sand | 7 | 45 | 91-97 | Anon., 1999 |
| starch potatoes | sand | 7 | 52 | 88-98 | Van Loon, 1995; Wijnholds, 1995, 1996, 1997 |
| | retained peat soil | 6 | 113 | 91-97 | Van Loon, 1995; Postma, 1995; Anon., 1999 |
| seed potatoes | clay | 6 | 21 | 92-97 | Anon., 1999 |
| garden pea | clay | 1 | 2 | 96 | Anon., 1999 |
| | sand | 7 | 28 | 91-97 | Anon., 1999 |
| perennial ryegrass | sand | 4 | 8 | 92-95 | Hofmeester, 1995 |
| oats | clay | 4 | 7 | 94-97 | Anon., 1999 |
| | sand | 2 | 2 | 97-98 | Anon., 1999 |
| iceberg lettuce | clay | 1 | 5 | 99 | Anon., 1999 |
| | sand | 19 | 83 | 85-87, 99 | Slangen, 1989, Anon., 1999 |
| root celery | clay | 1 | 5 | 92-97 | Anon., 1999 |
| fennel | sand | 1 | 1 | 97 | Kroonen-Backbier., 1999 |
| head lettuce | clay | 10 | 10 | 97-98 | Ehlert, 2001 |
| | retained peat soil | 1 | 1 | 97 | Ehlert, 2001 |
| | sand | 13 | 24 | 91-97 | Kroonen-Backbier,1999; Ehlert, 2001; |
| grain maize | sand | 4 | 60 | 93-96 | Van Dijk, 1997 |
| silage maize | clay | 8 | 83 | 85-94 | Schröder, 1990; Van der Schans, 1995; Van Dijk, 1996 |
| | loess | 4 | 64 | 95-98 | Geelen, 1999 |
| | sand | 99 | 773 | 75-99 | Schröder, 1985, 1987, 1989, 1990, 1992, 1993; Van Dijk, 1995, 1996, 1997, 1998; Van der Schans, 1995, 1998; Van der Schoot 2000; Anon., 1999 |
| leek | retained peat soil | 1 | 1 | 97 | Anon., 1999 |
| | clay | 12 | 25 | 89-98 | De Kraker 1993, Ehlert, 2001 |
| | sand | 8 | 28 | 91-99 | Kroonen-Backbier, 1999; Anon., 1999 |
| spinach | clay | 5 | 35 | 94-96 | De Kraker, 1997 |
| dwarf French bean | sand | 7 | 26 | 91-97 | Anon., 1999 |

| Crop | Soil | No. of trials | No of obs. | Years | Source |
|---|---|---|---|---|---|
| sugar beets | retained peat soil | 5 | 32 | 87-98 | Postma, 1995; Anon., 1999 |
| | clay | 12 | 179 | 87-97 | Hengsdijk, 1992; Westerdijk, 1992; Van Dijk, 1999; Anon., 1999 |
| | loess | 5 | 79 | 88-98 | Postma, 1995; Geelen, 1999 |
| | sand | 8 | 40 | 91-97 | Anon., 1999 |
| triticale | sand | 7 | 11 | 91-97 | Anon., 1999 |
| field beans | sand | 5 | 7 | 91-94 | Hofmeester, 1995 |
| carrot, fine | sand | 8 | 15 | 91-98 | Kroonen-Backbier, 1999; Anon., 1999 |
| winter oil-seed rape | sand | 2 | 3 | 92-93 | Hofmeester, 1995 |
| carrot, winter | clay | 13 | 16 | 92-98 | Ehlert, 2001; Anon.,1999 |
| | sand | 5 | 5 | 93-97 | Anon.,1999 |
| winter rye | sand | 7 | 11 | 94-98 | Hofmeester, 1995; Anon.,1999 |
| winter wheat | retained peat soil | 1 | 1 | 98 | Anon.,1999 |
| | clay | 20 | 77 | 91-98 | Darwinkel, 2000; Anon.,1999; Timmer, 1999 |
| | loess | 3 | 24 | 95-98 | Geelen, 1999 |
| | sand | 11 | 17 | 91-97 | Hofmeester, 1995; Anon., 1999 |
| witloof chicory | clay | 16 | 31 | 93-97 | Van Kruistum, 1997; Schober, 1998; Anon., 1999 |
| | loess | 2 | 10 | 91-93 | Postma, 1995 |
| white cabbage | clay | 4 | 44 | 92-93 | Everaarts, 1995 |
| seed onion | clay | 13 | 104 | 91-97 | De Visser, 1996; Anon.,1999 |
| spring barley | clay | 14 | 42 | 96-98 | Anon.,1999 |
| | sand | 3 | 6 | 96-98 | Anon., 1999 |
| spring wheat | clay | 4 | 9 | 94-97 | Anon., 1999 |

## 5.3 Procedure of analysis

In this chapter all relevant data sets have been analysed, aiming at predicting the $N_{min,H}$ under average conditions and at N-rates according to the guidelines for fertiliser recommendations in the Netherlands (Van Dijk, 1999). Besides the average $N_{min,H}$ its deviation has been estimated as well. Where possible, a distinction between soil type and growing period was made.

For this purpose, the following procedure has been followed:

1. The relation between the effective N-rate ($A$) and $N_{min,H}$ was fitted with the following non-linear model:

$$N_{min,H} = \alpha + \frac{\beta}{e^{\frac{\gamma}{A}} - 1} \qquad 5.1$$

with:

$\alpha$ = $N_{min,H}$ when $A$ approaches to 0

$\beta/\gamma$ = slope of the curve at large values of $A$

This relation was selected when: the values of the estimated parameters α and β/γ were realistic (i.e. >0 and within 0.2 – 1.0 respectively) and significant and when the correlation of this model was larger than the linear model described below.

2. When the previous conditions were not met, the relation between $A$ and $N_{min,H}$ was fitted with the following linear model:

$$N_{min,H} = \alpha + \beta * A \qquad 5.2$$

with:
$\alpha$ = $N_{min,H}$ at $A = 0$
$\beta$ = slope of the curve

This relation was used when the values of the estimated parameters $\alpha$ and $\beta$ were realistic (i.e. >0 and within 0.2 – 1.0 respectively) and $\beta$ was significant.

3. When no linear relation was found either, the average of all observations was used as an estimate for $N_{min,H}$. Other conditions included: the number of observations should exceed 5, the range in N-rate should be sufficient or the N-rate of most observations should be near the level of the recommended N-rates.

This procedure was followed per crop, while making a distinction between the type of soil (sand, loess and clay). For some horticultural crops with a short cropping period, also a distinction was made for the growing period (spring, summer and autumn). Subsequently, different types of soils, growing period periods and crops were clustered when:
a) the estimates for the parameters of the selected model or $N_{min,H}$ at recommended N-rates did not differ significantly (determined by a pair wise t-test);
b) the differences between the estimated $N_{min,H}$ at recommended N-rates were below 10 kg N/ha and;
c) no further reason exist to differentiate (related crops such as small grains).

For each crop-soil-growing period combination or cluster, a value for $N_{min,H}$ was calculated a farmer may expect to exceed once every 10 years when applying fertilisers at recommended rates. The credibility of these estimates relies much on the number of observations and their distribution over the years and locations.

The effect of summer precipitation on the relation between the effective N-rate and $N_{min,H}$ was analysed for maize and potatoes. Former research with maize (Schröder, 1998) showed that N-losses during the growing season were positively related to precipitation. Ware and starch potatoes as well as silage and grain maize were used for this exercise, since a large number of observations was available for these crops. Seed potatoes were excluded from this analysis since they are harvested much earlier. The factor precipitation was included in model 5.1 as follows:

$$N_{min,H} = \alpha * \rho^{(z-350)} + \frac{\beta * \rho^{(z-350)}}{e^{\frac{\gamma}{A}} - 1} \qquad 5.3$$

with
$\rho$ expressing the effect of the precipitation and
$z$ the amount of precipitation between planting and soil sampling at harvest. This amount is subtracted with 350, which is set as the average precipitation in the defined period.

## 5.4 Results

Table 5.2 shows an overview of the estimated $N_{min,H}$ –values at average conditions with N-rates according the recommendations. More details about the considered crop-soil-growing period combinations are presented in Appendices I and II. The extend to which the relation between the N-rate and $N_{min,H}$ could be described with the given non-linear and linear functions depended on: the number of observations, the ability of the crop to absorb nitrogen at increasing N-rates and the variation in N-rate of the observations.

Since the data set was based on a wide variation of trials, there is a chance that observed differences between crops, soil types and period of growing period result from other factors, which are unbalanced among the crop, soil and growing period combinations. This risk will decrease at increasing number of observations.

Figures 5.1 to 5.6 show the relation between the effective N-rate and $N_{min,H}$. These figures indicate that other factors play an important role as well. The differences in response between the crops were large. For example, potatoes and maize show higher $N_{min,H}$ -values than sugar beet and the small grains. The first two crops show also a stronger increase of $N_{min,H}$ with higher N-rates than the last two. For silage maize cultivated on sandy soils, at high N-rates, about 50% of the effective nitrogen applied in excess was recovered as $N_{min,H}$.

The soil type had a significant effect as well. Particularly for sugar beet, maize and winter cereals, higher $N_{min,H}$ -values were observed on sandy soils than on clay soils (Table 5.2). The results of the analysis per crop or cluster of crops are discussed below in more detail.

### Potatoes

A distinction was made between ware potatoes on sandy, loess and clay soils, starch potatoes on sandy soils and seed potatoes on clay soils. The $N_{min,H}$ -values for ware potatoes were estimated after merging the data sets from the different soil types. Insufficient differences between the different types of soil were observed to justify different $N_{min,H}$ -estimates for each type of soil (Fig. 5.1). The $N_{min,H}$ at the recommended N-rate was estimated at 68 kg N/ha for all soil types. The somewhat higher N-recommendation for sandy soils compared to those for clay and loess soils lead to a negligible difference in $N_{min,H}$.

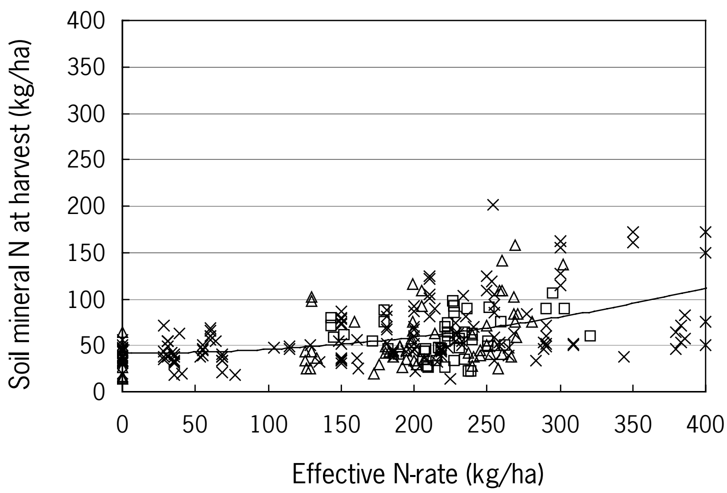


*Figure 5.1. The effect of the effective N-rate on the $N_{min,H}$ (0-60 cm) for ware potatoes on clay soils (x), sandy soils (□) en loess (Δ). The curve is an estimate with the non-linear model (Eq. 5.1) with data from all soil types.*

*Table 5.2. Overview of the estimated $N_{min,H}$-values (kg N/ha, 0-60 cm) for the considered crops and growing periods for different soil types under average conditions when nitrogen is applied according to the fertiliser recommendations (Van Dijk, 1999). The value that is expected to be exceeded once every ten years, is given in brackets.*

| Crop | Soil | | |
|---|---|---|---|
| | Clay | Loess | Sand |
| ware potatoes* | 68 (106) | 68 (106) | 68 (106) |
| starch potatoes | - | - | 41 (77) |
| seed potatoes | 55 (80) | - | - |
| sugar beet* | 15 (27) | 25 (57) | 25 (57) |
| silage and grain maize* | 41 (77) | 41 (77) | 76 (139) |
| winter cereals* | 22 (42) | 22 (42) | 36 (53) |
| spring cereals* | 17 (28) | 17 (28) | 17 (28) |
| perennial ryegrass | - | - | 19 (27) |
| seed onion | 60 (96) | - | - |
| cauliflower – summer and autumn | 58 (104) | - | - |
| broccoli – all growing periods*# | 39-50 (60-71) | - | 39-50 (60-71) |
| Chinese cabbage – all growing periods | - | - | 51 (99) |
| garden pea | - | - | 25 (36) |
| root celery | 39 (72) | - | - |
| iceberg lettuce – all growing periods# | - | - | 98-112 (186-225) |
| head lettuce – all growing periods* | 89 (133) | - | 89 (133) |
| leek – autumn* | 91 (152) | - | 91 (152) |
| spinach – all growing periods | 122 (246) | - | - |
| dwarf French bean | - | - | 45 (92) |
| field bean | - | - | 54 (88) |
| carrot, fine – autumn | - | - | 10 (17) |
| carrot, winter* | 24 (46) | - | 24 (46) |
| witloof chicory* | 24 (46) | 24 (46) | - |
| white cabbage | 27 (41) | - | - |
| Brussels sprouts | 7 (10) | - | - |

* *When similar values are given for different soil types, the estimates are based on the merged data sets from the soil types (see procedure in 5.2).*

\# *When differences in recommended N-rates for a crop-soil-growing period cluster lead to a relevant difference in $N_{min,H}$, its range is presented (details are shown in Appendix I).*

Starch and seed potatoes showed a different response to the N-rate than the one observed for ware potatoes. For starch potatoes $N_{min,H}$ was estimated to be about 20 kg N lower than the value for ware potatoes. A satisfactory explanation could not be given. Seed potatoes, with a much lower recommended N-rate, showed an $N_{min,H}$ -value in between those of the ware and starch potatoes.

The $N_{min,H}$ -values at recommended N-rates were calculated for average conditions. However, the variation in $N_{min,H}$ at a fixed N-rate is large. It was estimated that a farmer fertilising his/her ware potatoes with 245 kg N/ha (as recommended), can expect a $N_{min,H}$ -value exceeding 106 kg N/ha once every ten year.

### Sugar beet

This crop showed much lower $N_{min,H}$ -values than potatoes. Sugar beet showed a linear response to the N-rate even when it exceeded the recommended amounts by far (Fig. 5.2). This crop absorbs the available nitrogen stronger than potatoes. The nitrogen applied in excess is mainly taken up and stored in the leaves. A distinction could be made between growing period on sandy soils and loess and those on clay soils. $N_{min,H}$ at the recommended N-rate of 140 kg N/ha was estimated for sandy soils/loess and clay soils at 25 and 15 kg N/ha, respectively. For clay soils the risk of high $N_{min,H}$ -values is expected to be much lower than on the other soil types.

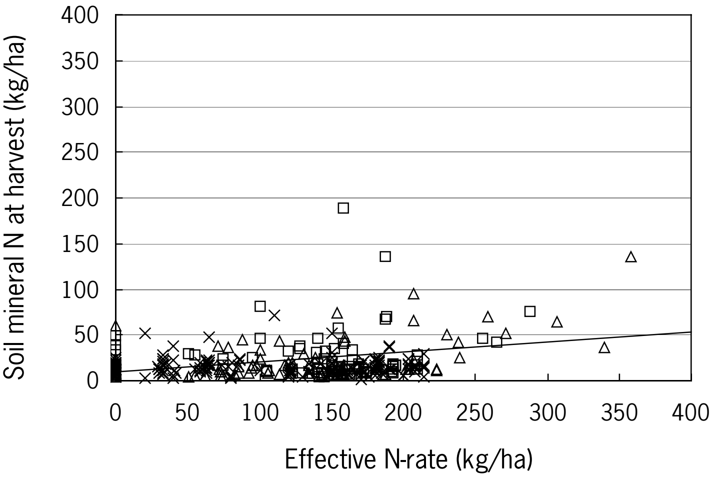


*Figure 5.2.* *The effect of the effective N-rate on the $N_{min,H}$ (0-60 cm) for sugar beet on clay (x), sandy (□) and loess soils (Δ). The line is an estimate with the linear model (Eq. 5.2) with data from sandy soils and loess.*

### Maize

By far most maize data originated from sandy soils. In these soils remarkably higher $N_{min,H}$ -values were found compared to those found for clay soils and loess (Fig. 5.3). The $N_{min,H}$ for sandy soils at the recommended N-rate was estimated at 76 kg N/ha, while those for clay soils and loess were about 35 kg lower. Even though the estimated $N_{min,H}$ for silage and grain maize differed considerably with 48 and 78 kg N/ha, the data sets were merged. The growing period conditions of silage and grain maize do not differ sufficiently to justify such a distinction. The higher $N_{min,H}$ -value for the sandy soil could possibly be a result of the manuring history of fields on which the trials were carried out. The estimated $N_{min,H}$ -values for clay soils and loess without N-application were very low (see Appendix I). In this case, these values were possibly underestimated as a result of the linear model used.

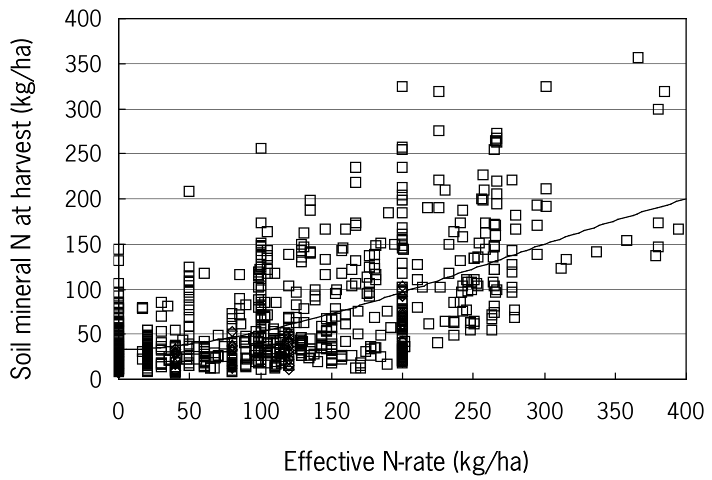


*Figure 5.3.* *The effect of the effective N-rate on the $N_{min,H}$ (0-60 cm) for silage and grain maize on sandy soils. The curve is an estimate with the non-linear model (Eq. 5.1).*

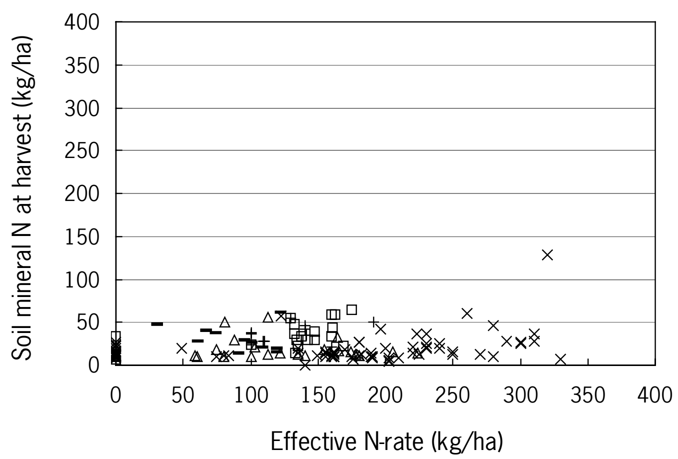


*Figure 5.4.* *The effect of the effective N-rate on the $N_{min,H}$ (0-60 cm) for winter cereals: winter wheat on clay (x), sandy (□) and on loess soils (Δ), rye on loess soils (-) and triticale on sandy soils (+).*

## Small grains

In this group of cereals (wheat, triticale, rye, barley, oats) only winter wheat on clay soils showed a significant response to the N-rate. However, the increase in $N_{min,H}$ of winter wheat was below 5 kg $N_{min,H}$ per 100 kg effective N-rate (Fig. 5.4). Small grains are well able to absorb the available soil nitrogen, even at high N-rates. For winter cereals on sandy soils the $N_{min,H}$ appeared higher than on loess and clay soils. For spring cereals no difference between the soils was found.

## Grass seed

Low values for $N_{min,H}$ were found after growing grass for seed production. For perennial ryegrass $N_{min,H}$ was estimated on 19 kg N/ha. This estimate was based on the average of the observations since no relation was found with the N-rate and most N-rates of the trials were near the recommended N-rate.

### Horticultural root crops

Witloof chicory , fine and winter carrots showed low levels of $N_{min,H}$, with averages below 25 N/ha. The $N_{min,H}$ of root celery is estimated at 39 kg N/ha, based on 5 observations in clay soils.

After growing seed onions on clay soils also high values of $N_{min,H}$ were observed. Compared to the situation without N-application, the $N_{min,H}$ increased with about 30 kg N/ha to 60 kg N/ha due to the recommended N-application of 110 kg N/ha.. The difference between onions and the other root crops as carrots and witloof chicory can possibly be explained by the earlier cessation of N-uptake by the onions.

### Legumes

Garden (vining) pea showed an average $N_{min,H}$ of 25 N/ha only. This is much below those for dwarf French bean and field bean which were associated with 45 and 54 kg $N_{min,H}$ respectively.

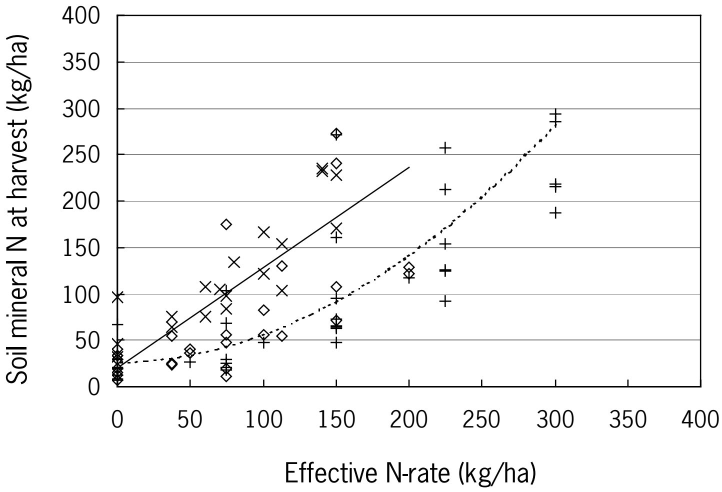


*Figure 5.5. The effect of the effective N-rate on the $N_{min,H}$ (0-60 cm) for iceberg lettuce: spring (+), summer (◊) and autumn crops (x).The curve is an estimate for the early crop with the non-linear model (Eq. 5.1), the straight line is an estimate for the summer and autumn crop combined with the linear model (Eq. 5.2).*

### Leafy vegetables

For most horticultural crops with a short growing period, no clear differences were observed between spring, summer and autumn growing periods. However, the limited number of observations combined with the large variation in $N_{min,H}$ -values at fixed N-rates complicated the search for possible effects of growing period. As a result, data sets for different growing periods were often merged. Even though $N_{min,H}$ -values for early crops which allow a subsequent crop within the same growing season are less interesting for this study, they have been included in the analysis in order to have sufficient observations.
For iceberg lettuce, a different response to the N-rate was found among the different growing periods (Fig. 5.5). The $N_{min,H}$ associated with a specific N-rate tended to be higher when the crop was grown later. This difference was mainly compensated since the N-recommendation for the late crops is lower than the early ones. Table 5.2 shows therefore a rather small range for the predicted $N_{min,H}$ for all growing periods (for details see Appendix I).

High $N_{min,H}$-values were observed for head lettuce, leek and spinach, with increasing values in the mentioned sequence. For spinach $N_{min,H}$ was possibly overestimated since they are based on estimates from observations of the 0-30 cm soil layer. Leafy vegetables do not use the applied nitrogen efficiently.

These crops are not harvested when the plant is at a mature stage but at a stage in which N-demand per unit time and rooth length is still large. This leads to high N-recommendations while the N-uptake by these type of crops is rather low. For spinach and leek a high N-supply is of extra importance for the greenness of the leaves, which is an important characteristic of quality.

For leek harvested in the period of January to May (Appendix I) the $N_{\mathrm{min,H}}$ provides little information on the risk of N-leaching in winter period. The observed $N_{\mathrm{min,H}}$ -values variated much and was not related to the N-rate.

### Cabbage

White cabbage showed a good capacity to absorb the applied nitrogen. Low values of $N_{\mathrm{min,H}}$ were found after the harvest of this crop. Compared to an unfertilised crop, $N_{\mathrm{min,H}}$ increased from 17 to 27 kg N/ha only when fertilised at the recommended N-rate of 280 kg N/ha. However, at higher N-rates, $N_{\mathrm{min,H}}$ increased much stronger. Up to 27% of the excess effective nitrogen was recovered as $N_{\mathrm{min,H}}$. A similar behaviour is expected for all types of head cabbages (such as red, savoy and pointed headed cabbage). For Brussels sprouts an average $N_{\mathrm{min,H}}$ -value of 7 kg N/ha was found on clay soils.

Cabbage types (such as broccoli, Chinese cabbage and cauliflower) that are harvested at a much earlier stage (during full growth) are less able to deplete the soil mineral nitrogen. For broccoli a higher $N_{\mathrm{min,H}}$ is expected after early crops than the late ones because higher N-rates are recommended for early than late crops (the recommended N-rate decreases due to the increasing amount of soil mineral-N when planted later). For cauliflower the same applies, but to a lesser extent than broccoli. An average of 58 kg $N_{\mathrm{min,H}}$ was estimated for the summer and autumn crops of cauliflower. For Chinese cabbage one $N_{\mathrm{min,H}}$ -value is presented in Table 5.2 for all growing periods, even though the recommended N-rates differ much among them. Due to the limited number of observations no relationship with the N-rate could be found. Broccoli and to a lesser extent cauliflower are crops that leave large amounts of nitrogen in the field as crop residues. A large part of this nitrogen is likely to mineralise and leach during autumn and winter. This issue is discussed in Chapter 6.

### Other crops

From other arable crops and field vegetables insufficient data were collected for reliable conclusions regarding $N_{\mathrm{min,H}}$.

### Ranking of crops

In Table 5.3, the various crops are grouped according to the expected $N_{\mathrm{min,H}}$ under average conditions at recommended N-rates. When the grouping applies to a specific soil type or growing period, this has been mentioned.

*Table 5.3. Ranking of crops according to the amount of $N_{min,H}$ (0-60 cm) at recommended N-rates. The crop-cultivation-soil combinations with the lowest $N_{min,H}$ are mentioned first within each category.*

| Category of $N_{min,H}$ (kg N/ha) | | | |
|---|---|---|---|
| < 30 (low) | 30 – 60 (medium) | 60 – 90 (high) | > 90 (very high) |
| Brussels sprouts, clay | winter cereals – sand | seed onion – clay | leek – autumn, clay/sand |
| carrot, fine – autumn, sand | broccoli – autumn, clay/sand | ware potatoes | iceberg lettuce |
| sugar beet – clay | root celery – clay | maize – sand | spinach – clay |
| spring cereals | silage maize – clay/loess | head lettuce – clay/sand | |
| perennial ryegrass – sand | starch potatoes – sand | | |
| winter cereals – clay/loess | dwarf French bean – sand | | |
| carrot, winter- clay/sand | broccoli - clay/sand | | |
| witloof chicory – clay/loess | Chinese cabbage – sand | | |
| garden pea – sand | field bean – sand | | |
| sugar beet – loess/sand | seed potatoes – clay | | |
| white cabbage – clay | cauliflower – summer/autumn, clay | | |

The category with the lowest $N_{min,H}$ -values consists of crops such as sugar beet and most of the cereals together with horticultural root crops like fine and winter carrot and witloof chicory. Perennial ryegrass for grass seed production, white cabbage and garden pea belong to this category as well.

The category indicated as medium comprises the cabbages with a short growing period, dwarf French bean, field bean, starch and seed potatoes, as well as the silage maize on clay soils and loess.

High $N_{min,H}$ -values can be expected after ware potatoes on all three types of soil, silage and grain maize on sand and seed onions on clay soils. Head lettuce formally belongs to this category with an estimated $N_{min,H}$ of 89 kg N/ha. However the characteristics of this crop are more typical for those of the highest category.

In the highest category, with $N_{min,H}$ above 90 kg N/ha, belong the leafy vegetables leek, iceberg lettuce and spinach.

### Effect of summer precipitation

The influence of precipitation was investigated with Eq. 5.3. This model is an elaboration of Model 5.1 with a non-linear precipitation factor. This model has been selected since it takes into account:

- the non-linear relationship with $N_{min,H}$ that was observed for potatoes and maize;
- the non-linear effect of precipitation on $N_{min,H}$ (i.e. depending on the effective N-rate and a decreasing effect at higher amounts of precipitation). As a result, the percentage of variance explained with Eq. 5.3 was higher than with Eq. 5.1, elaborated by a linear precipitation factor.

Table 5.4 shows the estimated effect of precipitation for maize and potatoes, taking into account the type of soil. Data sets with loess and clay soils have been merged since they did not show a different response to precipitation. Data sets with ware and starch potatoes have been merged for the sandy soils.

*Table 5.4. Effect of summer precipitation for maize and potatoes on clay, loess and sandy soils (see also Eq. 5.3).*

| Crop and type of soil | No.obser-vations. | Model parameters | | | Precipi-tation ($\rho$) | Standard error of $\rho$ | Pair wise t-test on | % decrease $N_{min,H}$ * per | |
|---|---|---|---|---|---|---|---|---|---|
| | | $\alpha$ | $\beta$ | $\gamma$ | | | soil type | 10 mm | 100 mm |
| ware potatoes on clay and loess soils | 230 | 44.5 | 44.5 | 203 | 0.9976 | 0.00033 | 2.4 | 2.4 | 21 |
| ware and starch potatoes on sandy soils | 210 | 36.9 | 781.5 | 1028 | 0.9960 | 0.00057 | (>95%) | 3.9 | 33 |
| silage maize on clay and loess soils | 147 | 15.9 | 83.0 | 217 | 0.9985 | 0.00073 | 1.7 | 1.5 | 14 |
| silage and grain maize on sandy soils | 773 | 31.8 | 60.3 | 135 | 0.9972 | 0.00025 | (>90%) | 2.8 | 24 |

* *Estimated decrease of $N_{min,H}$ (0-60 cm) due to the increase of precipitation of 10 and 100 mm respectively compared to the average of 350 mm in the period from planting to harvest.*

A significant precipitation effect on $N_{min,H}$ was found for both potatoes and maize. An increase of precipitation with 100 mm (above the average of 350 mm between planting and harvest) was estimated to decrease $N_{min,H}$ with 14% to 33%. Ware potatoes, for example, fertilised with the recommended amount of 245 kg N/ha may have 68 kg $N_{min,H}$ /ha under average conditions. After a wet summer with an additional precipitation of 100 mm in the period between planting and harvest, $N_{min,H}$ is expected to be 14 kg below this average. The opposite applies to a dry summer.

The effect of precipitation on $N_{min,H}$ appears larger for potatoes than maize. The same applies for sandy soils in comparison to clay soils and loess. The difference between soils is probably due to nitrate leaching, which losses are higher on lightly textured soils than on more heavy soils. Summer precipitation also affect denitrification losses and indirectly the N-uptake through factors such as water supply, temperature, radiation and risk of diseases that affect crop production. In the above analyses only the total precipitation has been considered, however the distribution of the precipitation is important as well. No satisfactory explanation can be given for the observed differences in precipitation effect between maize and potatoes.

## 5.5 An estimator for $N_{min,H}$ when experimental data are lacking

For major crops typical values for $N_{min,H}$ residues at harvest are available, as indicated in the present chapter. Trials on which these typical values are usually based, however, are lacking for a number of minor crops. So, in those cases a best guess must be made. Soil mineral N residues result from the discrepancy between the amount of N available to a crop and the amount of N taken up by it. The amount available can be approximated as the sum of soil mineral-N ($N_{min,S}$) in spring, N mineralised and deposited from spring to harvest and N applied with fertiliser:

$$\text{predicted } N_{min,H} = N_{min,S} + \text{N deposited} + \text{N mineralised} + \text{N fertiliser} - \text{N uptake} \quad 5.4$$

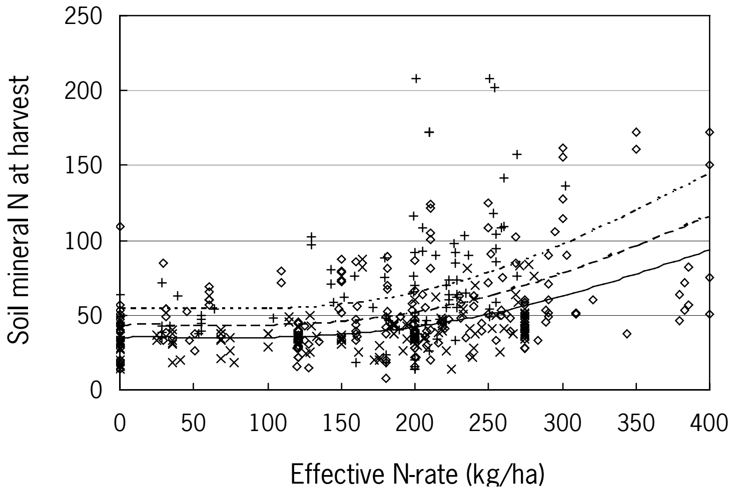


*Figure 5.6.* *Effect of summer precipitation on* $N_{min,H}$ *(0-60 cm) for ware and starch potatoes on all soil types combined. The observations are grouped according to the amount of precipitation: < 300 mm (+), 300-400 mm (◊) en > 400 mm. The curves are estimated with the non-linear model (Eq. 5.3) with amounts of summer precipitation of: 250 mm (—), 350 mm (---) en 450 mm (....).*

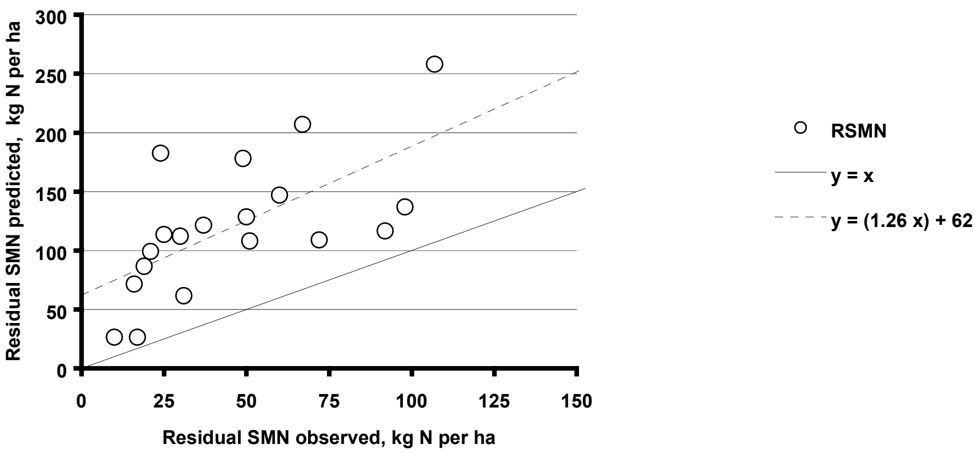


*Figure 5.7.* *Relationship between observed and predicted* $N_{min,H}$ *for nineteen major arable crops (see text for predictor formula).*

Assuming that:

- Nmin spring = 30 kg N per ha (Schröder, 1998),
- N deposited within growing season = 25 kg N per ha (Schröder, 1998)
- N mineralised within growing season = (days from planting to harvest) x 0.50 kg N per ha per day (Schröder, 1998)
- N fertiliser = crop specific N-recommendation (Van Dijk, 1999)
- N uptake = N removed with harvestable fraction and N in crop residues (Smit, 1994)

$N_{min,H}$ predictions were made for nineteen major arable crops. For the same nineteen crops, observed $N_{min,H}$ at recommended N rates were interpolated from the curves relating $N_{min,H}$ to the applied N rate (this chapter). The predicted values are plotted versus the interpolated values in Figure 5.7. Apparently, Eq. 5.4 overestimates residual $N_{min,H}$, possibly because it does not account for losses (including immobilisation) during the growing season. Nevertheless, Figure 5.7 provides a basis for estimating residual $N_{min,H}$ ($N_{min,H\ ,\ est}$) when values cannot be derived from experiments:

$$N_{min,H\ ,\ est} = \max\ (0, (\text{predicted } N_{min,H} - 62) / 1.26) \qquad 5.5$$

with predicted residual $N_{min,H}$ according Eq. 5.4.

## 5.6 Major conclusions

- For most crops, the residual soil mineral nitrogen at the time of harvest ($N_{min,H}$ ) is positively related to the N-rate.
- The expected amount of $N_{min,H}$ at recommended N-rates relies much on the type of crop, reflecting the variable ability of crops to absorb nitrogen. Consequently, 'safe' and 'risky' crops can be distinguished.
- For some crops an effect of soil type on the predicted $N_{min,H}$ was observed. The same applies to the period of growing for field crops with a short growing cylce. Summer precipitation is also of importance and negatively related to $N_{min,H}$.
- The large variation in $N_{min,H}$ observed at fixed N-rates complicates its prediction. Averaged for all crops studied, the predicted $N_{min,H}$ -value is expected to be 75% higher than the average value once in every 10 years, when a farmer fertilises his/her crop according to standard recommended practice.

# 6. Post-harvest changes in residual soil mineral nitrogen

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## 6.1 Introduction

The nitrate concentration of water leaving the root zone from fall to spring is not just determined by the soil mineral N supply in the upper soil layers at harvest, but also by 1) the amount of soil mineral N that has left these layers beforehand (pre-harvest losses) and 2) the soil mineral N supply that becomes effectively available during the period from fall to spring. The latter supply is determined by:

- fertiliser management (nature, rate, timing, placement) from harvest to tillage,
- quantity, nature and management of green manures or cover crops,
- quantity, nature and management of crop residues,
- mineralisation from organic matter (humus) and the effect of cultivation on this,
- quantity and distribution of precipitation from harvest to spring.

Figure 1.2 (chapter 1) presents an overview of the processes affecting $N_{min,H}$, including those preceding harvest. As indicated in Chapter 1, similar N rates do not necessarily bring about the same $N_{min,H}$ supply, as crops differ in their ability to intercept N and translocate this N to harvestable plant fractions (Prins *et al.*, 1988; Goosensen & Meeuwissen, 1990; Neeteson, 1994). The non-harvested crop residues may act as a sink or a source of soil mineral N after harvest. The same applies to green manures and cover crops (Schröder et al., 1996a; -, 1997a).
This paragraph addresses what may be called the effective $N_{min,H}$ from harvest to early winter. It deals with the processes altering the $N_{min,H}$ that is initially present at harvest. We intend to present some simple rules of thumb indicating what kind of corrections should be made in order to translate measured $N_{min,H}$ 's at harvest into effective $N_{min,H}$. This effective $N_{min,H}$ may show a better relationship with measured nitrate concentrations of the upper groundwater. Or in other words, we attempt to reduce the variation observed between both in empirical datasets (as shown in Figure 8.2, Chapter 8). Mind that this chapter does not address the sources of variation which determine the $N_{min,H}$ supply for a given crop, such as the fertiliser regime, summer precipitation, etc. Those aspects were dealt with in Chapter 4.

## 6.2 Increase of $N_{min,H}$ due to fertiliser use

On sandy soils in The Netherlands, the application of animal manure after harvest is permitted until 1 September. The use of mineral fertiliser-N may even take place after this date. Hence, the $N_{min,H}$ may rise due to manure-N and fertiliser-N applications. The extent to which this occurs depends on the rate, nature, timing and method of application. When manure is the source of N, the increase equals the sum of two terms: 1) rate x $NH_4$N-concentration minus volatilisation loss (i.e. 10-20% of $NH_4$-N content according to Steenvoorden et al., 1999)), and 2) rate x easily degradable organic N concentration x fraction mineralising within the given period of time (Beijer & Westhoek, 1996). When mineral fertiliser is the source of N, only term 1) (including $NO_3$-N component of the fertiliser) is relevant. The increase due to the use of animal manure before or during the growing season can be estimated with term 2). Rijtema presented a calculation method to estimate the monthly breakdown of organic N in manures (Lammers, 1983). As and example, Table 6.1 shows the mineralisation dynamics of organic N in manure of monogastrics for various times of application.

*Table 6.1. Mineralisation of the easily degradable organic N fraction in animal manure of monogastrics in % of this N pool per month, as related to the time of application (after Lammers, 1983).*

| Application | Month: | | | | | | |
|---|---|---|---|---|---|---|---|
| | Aug | Sept | Oct | Nov | Dec | Jan | Feb |
| 1 March | 12 | 7 | 4 | 2 | 1 | 1 | 1 |
| 1 August | 29 | 17 | 9 | 5 | 3 | 3 | 3 |
| 1 September | | 23 | 12 | 7 | 4 | 4 | 4 |
| 1 October | | | 15 | 8 | 6 | 4 | 4 |
| 1 November | | | | 10 | 6 | 5 | 5 |
| 1 December | | | | | 7 | 6 | 6 |

According to this approximation, estimates can be made for the amount of N liberated from manures in a given period. When applied around 1 March, 17% of the easily degradable organic N fraction in manure of ruminants will mineralise between 1 September and 1 December, whereas 36% will be mineralised during this period when applied around 1 September. Corresponding figures for manure of monogastrics are 13 and 41%. Implications in terms of kg N per 10 $m^3$ of manure are presented in Table 6.2. If one is rather interested in the mineralisation rate in a steady state situation (i.e. when the accumulated contributions of previously applied resistant organic N fractions is also considered relevant), the values presented in Table 6.2 need multiplication by a factor 2 for the manure of ruminants, 1.5 for the manure of monogastrics, 1.4 for cereal straw, 1.33 for green manures, and 1.25 for plant material rich in N (Lammers, 1983; Janssen & Van Reuler, 1986). Mind, that we assume here that the degradation of plant residues follows that of manure from monogastrics. The various manures (animals, plant materials) just differ in terms of the ratio between the easily degradable (so-called Ne) and resistant (so called Nr) fraction, the ratio being highest for plant material.

*Table 6.2. Mineralisation of easily degradable organic N in animal manure (kg N per month per 10 $m^3$), as affected by manure type and time of application (after Lammers, 1983), assuming that manure from cattle, pigs and poultry contains 12, 20 and 29 kg easily degradable N per 10 $m^3$ (Beijer & Westhoek, 1996).*

| Manure type | Time of application | Month: | | | | | |
|---|---|---|---|---|---|---|---|
| | | Sept | Oct | Nov | Dec | Jan | Feb |
| Cattle | 1 March | 1.0 | 0.6 | 0.3 | 0.2 | 0.2 | 0.2 |
| | 1 September | 2.2 | 1.2 | 0.7 | 0.5 | 0.4 | 0.4 |
| Pigs | 1 March | 1.5 | 0.8 | 0.4 | 0.3 | 0.2 | 0.2 |
| | 1 September | 4.6 | 2.4 | 1.3 | 0.9 | 0.7 | 0.7 |
| Poultry | 1 March | 2.2 | 1.2 | 0.6 | 0.4 | 0.3 | 0.3 |
| | 1 September | 6.7 | 3.5 | 1.9 | 1.3 | 1.0 | 1.0 |

## 6.3 Decrease of $N_{min,H}$ due to plant cover

After harvest the soil may become covered again by fallen seeds ('volunteers'), by weeds, or by purposively planted green manures including catch crops. Catch crops are defined here as cover crops that derive their N fully from residual $N_{min,H}$.

Schröder *et al.* (1996a) showed that the aerial N yield (kg N/ha) of a cover crop grown under a moderate N supply can be described as 14 + (0,14 x heatsum (> 5 $^{o}$C)) from the harvest of the preceding main crop to the date of cover crop incorporation). This implies that a cover crop will not take up N from November 1 to March 15 under average conditions in The Netherlands. Therefore, N uptake strongly depends on planting date. On average, the aerial N yield associated with planting dates of August 15, September 15 and October 15, amount to 76, 33 and 2 kg N per ha, respectively. An additional amount of 10-20 kg N per ha is invested in stubble and roots (Schröder, 1997). Consequently, the total N uptake rate from August to October is approximately 1.3 kg N per ha per day for these types of catch crops. An amply fertilised green manure cover crop undersown in cereals may take up much more N. This type of cover crops can assimilate up to 100 kg N per ha from mid August to the beginning of November (Schröder *et al.*, 1997). Including roots and stubble, uptake rates of these crops may amount to circa 1,6 kg N per ha per day.
A literature review of Schröder (1987) showed that a reduction of the growing season by one day, reduced the dry matter yield of rye grown for forage by 95 kg per ha. Assuming an N content of 3% in forage rye (Schröder, 1997), such a reduction would be equivalent to an N uptake rate of even 2.9 kg N per ha per day.
We conclude that a cover crop take up 1.5-2.5 kg N per ha per day in aerial and subterranean plant parts together in the period from Augustus to October. The lower boundary applies to environments with a moderate N supply, the upper boundary to environments in which there is ample N available and in which temperature and radiation are not below normal values. In the range where N is limiting production, recovery of residual soil mineral N ($N_{min,H}$) by cover crops is circa 70% (Schröder *et al.*, 1997).

## 6.4 Changes of $N_{min,H}$ due to immobilisation by or mineralisation from crop residues

Incorporation of crop residues low in N may sequester soil mineral N. Stouthart & Leferink (1992) indicate that one ton of cereal straw (dry matter content of 85%) contains 3.5 to 5 kg N, implying an N concentration of 0.4-0.6% in the dry matter. If one assumes that dry matter consists of 40% carbon (C) (Klimanek, 1990; Thorup-Kristensen, 1994; Wyland *et al.,* 1995), C:N ratios in straw amount to 67-100. Such values agree with a value of 80 given by Janssen & Van Reuler (1986). Based on the assimilation-dissimilation ratio and C:N ratio in micro organisms presented in Janssen & Van Reuler (1986), it can be calculated that 7.5 ton straw dry matter is associated with 3000 kg C and that such an amount will immobilised 100 kg N before any net N mineralisation occurs. As straw itself contains 34 kg, another 66 kg N must be provided from the soil. Schröder *et al.* (1997) showed that green manures with a C:N ratio of circa 30 in the aerial plant parts (and >30 in the whole crop) tended to immobilise N until the spring following their incorporation in the preceding fall. Hence, we assume that cereal straw too will immobilise N during fall and winter and that it will last until the next growing season before the sequestered N will be re-mineralised.
Most other crop residues have higher N concentrations than 1.33% and lower C:N ratios than 30. So, the probability of net mineralisation before winter is considerably larger than with cereal straw. The extent to which this occurs depends on the N concentrations and the moment at which the residues are exposed to degradation. Obviously, the absolute impact of this process also depends on the magnitude of the crop residues. We used data from Smit (1994) to estimate the N yield and N concentration of crop residues. We assumed the Ne:Nr ratio to depend on the N concentration according to:

Ne/Nr=3 for N%<2, Ne/Nr = N%+1 for 2<N%<3 and Ne/Nr=4 for N%>3

Subsequently, we made an estimate of the N-mineralisation from incorporated residues from harvest to 1 December, based on the average time of harvest. Table 6.1 was used for the calculations. Table 6.3 shows the results.

*Table 6.3. Residue characteristics and estimated mineralisation of easily degradable organic N ('Ne') from crop residues (kg N per ha) from harvest to 1 December.*

| Crop type | Harvest date | Characteristics of residues: | | | | Mineralisation |
|---|---|---|---|---|---|---|
| | | DM, kg per ha | Total N, kg per ha | Ne, kg per ha | C:N ratio | Up to 1 Dec. kg N $ha^{-1}$ |
| Winter wheat | 15 August | 3740 | 19 | 13 | 79 | -31 |
| Spring barley | 10 August | 2700 | 14 | 9 | 79 | -22 |
| Winter barley | 25 July | 3570 | 18 | 12 | 79 | -30 |
| Winter rye | 1 August | 3830 | 19 | 13 | 79 | -32 |
| Silage maize | 15 September | 500 | 6 | 4 | 33 | 1 |
| Sugar beets | 25 October | 4000 | 120 | 90 | 13 | 11 |
| Potatoes | 15 August | 1000 | 20 | 13 | 20 | 6 |
| | 20 September | 1000 | 20 | 13 | 20 | 4 |
| | 1 October | 1000 | 20 | 13 | 20 | 3 |
| | 10 October | 1000 | 20 | 13 | 20 | 3 |
| Onions | 1 September | 1000 | 5 | 3 | 80 | 1 |
| Carrots | 15 September | 300 | 10 | 8 | 12 | 2 |
| | 1 November | 3100 | 40 | 27 | 31 | 3 |
| Cichory | 1 November | 2300 | 44 | 29 | 21 | 3 |
| Brussels sprouts | 25 August | 8600 | 135 | 90 | 25 | 40 |
| | 1 October | 8600 | 135 | 90 | 25 | 21 |
| Ice berg lettuce | 15 June | 1700 | 70 | 53 | 10 | 50 |
| | 1 August | 1700 | 70 | 53 | 10 | 31 |
| | 25 September | 1700 | 70 | 53 | 10 | 14 |
| Broccoli | 10 August | 3700 | 155 | 116 | 10 | 62 |
| Cauliflower | 15 August | 3500 | 120 | 90 | 12 | 45 |
| Celeriac | 15 November | 3300 | 75 | 52 | 18 | 3 |
| Leek | 1 October | 1700 | 60 | 45 | 11 | 11 |
| Chinese cabbage | 25 July | 1500 | 65 | 49 | 9 | 31 |
| | 15 September | 1500 | 65 | 49 | 9 | 16 |
| Vining peas | 1 July | 6300 | 188 | 141 | 13 | 116 |
| Snap beans | 1 October | 2900 | 95 | 71 | 12 | 17 |
| White cabbage | 10 November | 4300 | 115 | 84 | 15 | 6 |
| Green manure, low N | 1 November | 2500 | 50 | 38 | 20 | 3 |
| Green manure, high N | 1 November | 3000 | 90 | 72 | 13 | 7 |

## 6.5 Mineralisation from 'old' organic matter

In the preceding sections short-term $N_{min,H}$ changes due to cover cropping and additions of fresh organic matter (manures, crop residues) were evaluated. Ultimately, organic inputs are all converted to humus. Humus too is subjected to further degradation. The annual breakdown of humus amounts to 1-2%. So, assuming an organic matter content of 1-3% and a soil bulk density of 1,35-1,45 kg per litre, 150-800 kg organic matter will be broken down per year per 10 cm soil layer. As organic matter contains 3-4% N, 4-32 kg N will be mineralised per ha per year per 10 cm layer. Typical for most soils is a mineralisation rate of 50-150 kg N per ha per year, equivalent to average rates of 0.14-0.41 kg N per ha per day. As mineralisation is temperature dependent, mineralisation rates follow seasonal patterns (Table 6.4).

*Table 6.4. Daily mineralisation rate (kg N per ha per day) as related to monthly temperatures (after Rijtema in Lammers (1983), assuming annual mineralisations of 50, 100 and 150 kg N per ha).*

| Mineralisation kg per year | Month | | | | | | | | | | | | average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| | [1.7°C] | [2.0°C] | [5.0°C] | [8.5°C] | [12.4°C] | [15.5°C] | [17.0°C] | [16.8°C] | [14.3°C] | [10.0°C] | [5.9°C] | [3.0°C] | |
| 50 | 0.05 | 0.05 | 0.07 | 0.10 | 0.16 | 0.23 | 0.27 | 0.26 | 0.20 | 0.12 | 0.08 | 0.06 | 0.14 |
| 100 | 0.09 | 0.10 | 0.14 | 0.21 | 0.32 | 0.45 | 0.53 | 0.52 | 0.40 | 0.25 | 0.15 | 0.11 | 0.27 |
| 150 | 0.14 | 0.15 | 0.21 | 0.31 | 0.48 | 0.68 | 0.80 | 0.78 | 0.60 | 0.37 | 0.23 | 0.17 | 0.41 |

Despite the incomplete recovery of mineralised N by crops, the N yield of unfertilised crops often exceeds 100 kg N per ha. The reason for this is that N in those treatments is not only provided by mineralization but also by the residual effect of manure applied in earlier years and the mineralisation of organic matter on reclaimed soils (e.g. peat soils). The availability of N is further increased by atmospheric N deposition (at present estimated at circa 0.1 kg N per ha per day in The Netherlands).

## 6.6 Effects of soil tillage

Mineralisation from organic matter can be promoted upon degradation of soil aggregates. Probably, this is due to improved gas exchange and to lift mechanical protection. Mineralisation can also increase when relatively dry crop residues are incorporated into a relatively moist soil. Tillage has an effect on both the degradation of aggregates and the incorporation of residues. Postponement of tillage until soil temperatures have dropped may hence reduce fall mineralisation and the subsequent loss of soil mineral N (Silgram & Shepherd, 1997). Stokes *et al.* (1992) showed that tillage may indeed promote the release of N from crop residues rich in N. They observed an effect due to tillage of circa 30 kg N per ha. Experiments must be interpreted with great care, however. Stenberg *et al.* (1999), for instance, showed that increased mineralisation associated with tillage resulted from the destruction of a spontaneous weed cover acting as a sink for soil mineral N rather than from tillage as such.

## 6.7 Summarising

$N_{min,H}$ dynamics after harvest depend on many factors. These factors have been addressed in the previous sections. Without N application in the period from harvest until late fall, the nature and management of crop residues will determine whether the $N_{min,H}$ changes. Timely incorporated crop residues which are rich in N do not necessarily result in a rise of $N_{min,H}$ supply, as mineralised N may be lost through leaching and denitrification. The magnitude of these losses depends on the extent to which the profile is refilled with water.
Most likely, precipitation after harvest has a similar effect on $N_{min,H}$ dynamics as precipitation has before harvest. Research indicated that any 10 mm increase of the long-term average summed precipitation during the growing season, may reduce the $N_{min,H}$ in the upper 60 cm layer by 2,5-4,0 kg N per ha (Schröder *et al.*, 1993; Schröder, 1999; Schröder *et al.*, 1996a; Schröder *et al.,* 1996b).

Finally, we would like to present a calculation example illustrating the effects of the processes involved:

Spring wheat grown on a sandy soil is harvested mid August. The straw yielding 7 tons per ha is chopped. Subsequently, 20 $m^3$ pig slurry per ha is applied and a cover crop is planted. The cover crop emerges around September 1. Further assumptions:
- straw is a stronger sink for N than a cover crop,

| | |
|---|---|
| - Nmin at harvest after spring wheat: | 30 kg N per ha, |
| - input with pig slurry: | 84 kg mineral N and 40 kg easily degradable organic N per ha, |
| - volatilisation loss from pig slurry: | 15% of the mineral N input, |
| - mineralised fraction of organic N in pig slurry between September 1 and December 1: | 42% of the easily degradable organic N, |
| - atmospheric deposition: | 0.1 kg N per ha per day, |
| - mineralisation from humus: | 0.2 kg N per ha per day, |
| - leaching and denitrification losses: | nil |
| - potential uptake rate cover crop: | 2,5 kg N per ha per day (until November 1) provided that sufficient (=calculated potential uptake/ uptake efficiency) soil mineral N is available |
| - uptake efficiency of cover crop: | 70%, |

implying:

- available $N_{min,H}$ (kg per ha) on December 1:

| | | |
|---|---|---|
| - input (I): | initial supply after wheat | 30 |
| | mineral N in pig slurry | 84 |
| | mineralised N from slurry | 17 |
| | deposition | 9 |
| | mineralised from humus | 18 |
| - output (O): | immobilised in straw | 49 |
| | taken up by cover crop | 67 |
| | losses due to volatilization | 14 |
| | losses due to leaching and denitrification | 0 |
| - net effect from August 15 to December 1 (I minus O): | | 28 |

## 6.8 Conclusion

Soil mineral N assessments at harvest can be characterised as ‘snap shots’. By nature, they do not reflect exactly how much N eventually will be exposed to overwinter leaching losses. However, reasonable estimates can be made of the magnitude of processes modifying the soil mineral N supply between the time of harvest and the onset of the leaching season. Hence, soil mineral N assessments are definitively not just a lottery.

# 7. Accumulation of residual mineral nitrogen under grazing regime

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## 7.1 Introduction

Chapter 3 and 4 dealt with accumulation of mineral nitrogen ($N_{min,H}$) on grassland under cutting conditions. However, the majority of the grassland area in the Netherlands is used for both grazing and cutting. Typical grassland management consists of one to three silage cuts per year, alternated with two to five grazing events per year. In this chapter grazed grassland is defined as grassland that is grazed at least once, irrespective of the number of grazing events or silage cuts.
On grazed grassland, the main nitrogen inputs are fertiliser, slurry and animal excreta (faeces and urine). The nitrogen outputs consist of animal intake and removal of cut grass, usually as silage.
Vellinga *et al.* (1997;2001) have developed the so-called NURP model (Nitrogen, URine and Pastures). The model distinguishes two main sources of accumulation of mineral N: (i) through urine and (ii) through fertiliser and slurry.

## 7.2 Accumulation of mineral N under urine spots

The nitrogen excretion through urine is calculated as follows: Nurine = Nintake – Nmilk – Nmeat – Nfaeces. These nitrogen input and output parameters have been calculated for cows with annual milk production levels of 4500 to 7000 kg per cow and for growing young stock, fed on rations containing herbage, silage and concentrates has been calculated. Individual animal data have been translated to dairy herd level, taking into account a temporal calving pattern and age distribution (Table 7.1). The number of urinations per cow per day, in which the nitrogen from urine is excreted, is derived as follows:

#urinations = (urine production/urine per urination) = (10 + Nurine x 0.1)/3.5 (7.1)

| | |
|---|---|
| #urinations | [$cow^{-1}$ $d^{-1}$] |
| urine production | [l $cow^{-1}$ $d^{-1}$] |
| urine per urination | [l] |
| Nurine | [g $cow^{-1}$ $d^{-1}$] |

*Table 7.1. Nitrogen excretion, urine production, nitrogen content of urine, number of urinations, and nitrogen 'load' by urine,as calculated by the dairy herd model in relation to fertiliser application level on grassland.*

| Indication fertilisation level ($kg.ha^{-1}year^{-1}$) | 100 | 225 | 350 | 450 |
|---|---|---|---|---|
| Nitrogen excretion in urine ($g.cow^{-1}day^{-1}$) | 250 | 300 | 350 | 400 |
| Urine production ($l.cow^{-1}d^{-1}$) | 35 | 40 | 45 | 50 |
| N-concentration in urine ($g.kg^{-1}$) | 7.14 | 7.50 | 7.78 | 8.00 |
| Number of urinations | 10 | 11.4 | 12.9 | 14.3 |
| Nitrogen 'load' under urine spots ($kg.ha^{-1}$) | 368 | 387 | 399 | 411 |

For each individual grazing event the NURP-model calculates the area affected by urine depositions. The urine-affected area is calculated with a simple non-overlap function, assuming that the area affected by one urination is 0.68 $m^2$. The grazing system defines the time spent grazing and the proportion of urine excreted in the field (Table 7.2).

*Table 7.2. Grazing time, the proportion of urinations deposited in the paddock and the potential supplementation.*

| Grazing system | Grazing time (hours/d) | Urinations in paddock (%) |
|---|---|---|
| Day and night | 20 | 90 |
| Day | 8 | 50 |
| Half day | 4 | 25 |

So for example, a grazing event of four days, day-and-night grazing, with 25 cows on a paddock of one ha, with 12 urinations per cow per day, results in a urine-affected area of 734 $m^2$ (7%). After seven consecutive grazing events, this approach generates areas of 59, 33, 8 and 1% affected by either 0, 1, 2 or 3 urine depositions, respectively.

The N uptake on urine-affected areas is calculated as the sum of the 'normal' N uptake found on unaffected areas and the additional nitrogen uptake from urine-N. The additional nitrogen uptake is derived from experiments with artificial urine (Figure 7.1). The additional nitrogen uptake decreases with increasing urination date.
As and option, the NURP-model allows negative effects of urine scorch. The proportion of urine scorch following urinations in June, July and August is assumed to be as follows:

$Scorch_{urine} = 25 \times (N_{applied} - 200)$, (7.2)
$Scorch_{urine}$ [%]
$N_{applied}$ [kg ha$^{-1}$ year$^{-1}$]

The minimum value for scorch is 0%. In urine-scorched grass, nitrogen uptake from urine and from fertiliser is reduced to zero.

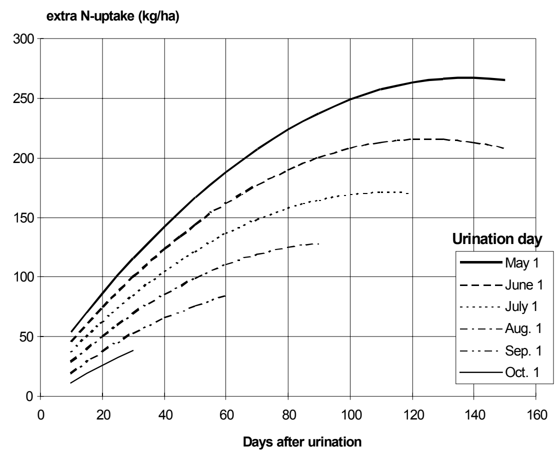


*Figure 7.1. Cumulative additional N uptake in urine spots at different urination dates at a fertilisation level of 200 kg N per ha per year. Nitrogen load in the urine spot is equivalent to 400 kg N per ha.*

Finally, the additional mineral nitrogen under urine-affected areas is calculated with the following relation, as shown in Figure 7.2,

$N_{min,H} = Nurine \times (-0.296 + 1.2979/ (1 + 0.01841 \times \text{days after urination})$ (7.3)
$N_{min,H}$ [kg ha$^{-1}$]

Nurine [kg $ha^{-1}$]

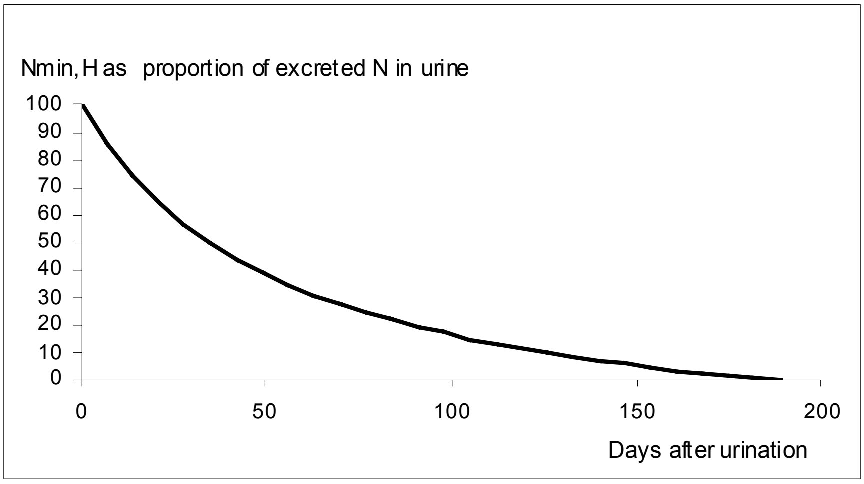


*Figure 7.2. Mineral nitrogen in the autumn under urine spots as a function of days after urine deposition.*

## 7.3 Accumulation of mineral N under cutting management

Data of cutting experiments on sand and clay soils have been analysed to predict mineral nitrogen (0-100 cm) in the autumn using, nitrogen application, nitrogen uptake and mineral nitrogen in spring. Regression analysis resulted in the following relationships (Figure 7.3):

Sand: $N_{min,H}$ = -54.5 + 88.3 x exp(-0.0116678xNsurplus) + 0.774 x Nsurplus (7.4)

Clay: $N_{min,H}$ = -476 + 494 x exp(-0.002473xNsurplus) + 1.211 x Nsurplus (7 5)
($R^2$ = 0.85; residual mean square = 47.2)

where,

Nsurplus = Nmin,spring + Napplied x (1 - ANR) (7.6)
= Nmin,spring + Napplied – Nuptake + Nuptake_N0 (7.7)

$N_{min,H}$ [kg.$ha^{-1}$ ]
Nsurplus [kg $ha^{-1}$ $year^{-1}$]
Napplied [kg $ha^{-1}$ $year^{-1}$]
Nuptake [kg $ha^{-1}$ $year^{-1}$]

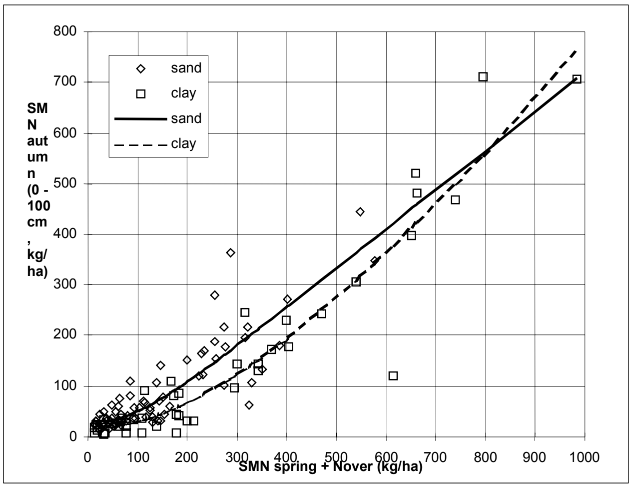


*Figure 7.3.* *Relationship between the sum of (Soil Mineral Nitrogen in spring and nitrogen not recovered in the crop) and SMN in autumn in the layer of 0 - 100 cm. Dots are experimental data, lines are regression lines.*

## 7.4 Paddock model

The relationships between $N_{min,H}$ and Nsurplus and between $N_{min,H}$ and excreted urine-nitrogen were incorporated in the grass production model. The grass production model describes daily grass growth and nitrogen uptake as a function of soil type, ground water level, nitrogen application, NMINspring and soil nitrogen supply.

The paddock model can be used to describe the effects of factors, such as nitrogen application, grazing system, milk production level or drought, on the accumulation of mineral nitrogen. However, the results of these calculations have to be treated with some caution, because the results of individual paddocks can not be translated directly to the farm level. For instance, a higher nitrogen application increases the accumulation of mineral nitrogen, under cutting and under grazing management (Figure 7.4). In this example it is assumed that, under grazing, the increased nitrogen application results to more cow grazing days. In reality the number of cow grazing days is more or less fixed, and increased grass production will lead to more cutting for silage.

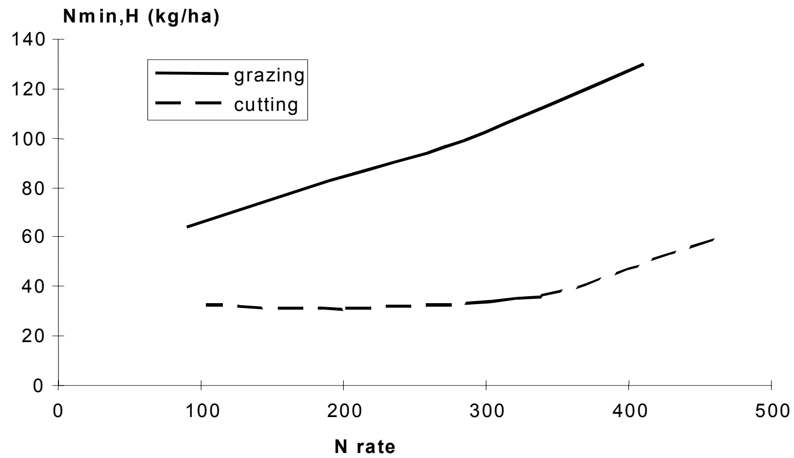


*Figure 7.4.* $N_{min,H}$ *as a function of nitrogen application, under grazing (day and night) or under cutting.*

Reducing the length of the grazing season in the autumn is an effective way to reduce the accumulation of mineral nitrogen. Excretions of urine in the autumn have only minor additional effects on the nitrogen uptake of grass, but have a major additional effect on $N_{min,H}$. An earlier end of the grazing season of one month reduces the accumulation of mineral nitrogen by 10 kg.ha$^{-1}$ (Figure 7.5).

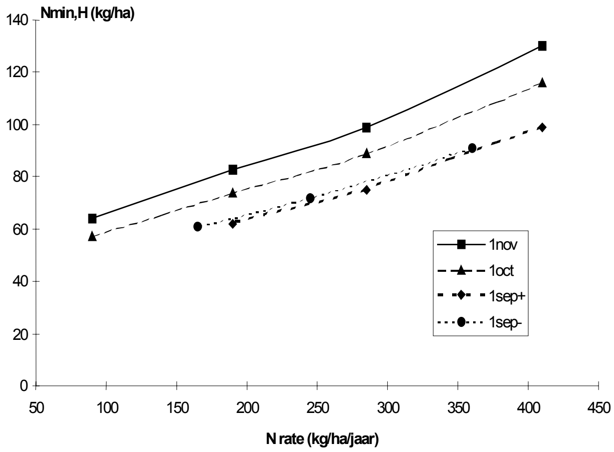


*Figure 7.5.* $N_{min,H}$ *as a function of the length of the grazing season, in a system with day and night grazing.*

## 7.5 Farm model (NURP)

To overcome the shortcomings of the paddock model, a simplified farm approach was developed. Mineral nitrogen in the autumn ($N_{min,H}$) is calculated with the following input data: grassland area, number of cows and young stock, nitrogen application level, drought sensitivity, grazing system, milk production level and supplemental feeding.
For these examples, the following assumptions have been made for the calculations with NURP:

- Milk production per cow is 8000 kg,
- Annual replacement rate of dairy cows is 30 %,
- Heifers graze day and night until 1 November,
- Calves graze day and night until 16 September,
- Drought sensitivity is zero,
- Soil nitrogen supply is 140 kg ha$^{-1}$.year$^{-1}$.

The 'basic' accumulation of mineral N is only determined by the level of nitrogen application, and is equal to 30, 33 and 40 kg N ha$^{-1}$, after application of 160, 250 and 340 kg ha$^{-1}$, respectively. Stocking rate and grazing system have there effects on the accumulation of mineral nitrogen under urine spots. Together, the ranges in nitrogen application, stocking rate and grazing system result in a range of $N_{min,H}$ of 44 to 109 kg ha$^{-1}$ (Figure 7.6).

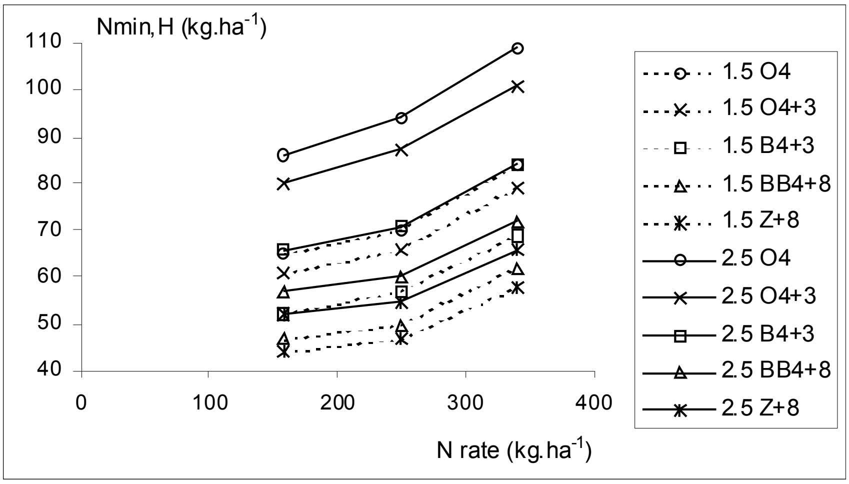


*Figure 7.6.* $N_{min,H}$ *in relation to stocking rate, grazing system and nitrogen application.O4=day-and-night grazing, B=daytime grazing only, BB=4 hours grazing, Z=zero grazing, + X = supplemental feeding of X kg of maize silage (kg DM cow*$^{-1}$*.day*$^{-1}$*).*

In practice, not all combinations of stocking rate, grazing system and nitrogen application are possible. The higher the stocking rate, and the lower the nitrogen application, the lower the possibilities for grazing. In a system with day-and-night grazing without maize supplementation, stocking rates up to 3.5 cows.ha$^{-1}$ are possible (Table 7.3). Higher stocking rates are only possible when the grazing time is restricted.

*Table 7.3.* $N_{min,H}$ *in relation to stocking rate, grazing system and nitrogen application.*

| | | Stocking rate | | | | |
|---|---|---|---|---|---|---|
| Grazing system | N rate (kg.ha$^{-1}$) | 1.5 | 2.5 | 3.5 | 4.5 | 5.5 |
| O4 | 159 | 65 | 86 | | | |
| | 250 | 70 | 94 | 118 | | |
| | 340 | 84 | 109 | 134 | | |
| O4+3 | 159 | 61 | 80 | 99 | | |
| | 250 | 66 | 87 | 108 | 129 | |
| | 340 | 79 | 101 | 123 | 145 | |
| B4+3 | 159 | 52 | 66 | 80 | | |
| | 250 | 57 | 71 | 85 | 100 | |
| | 340 | 69 | 84 | 99 | 114 | |
| BB4+8 | 159 | 47 | 57 | 66 | 76 | |
| | 250 | 50 | 60 | 71 | 81 | 90 |
| | 340 | 62 | 72 | 83 | 93 | 102 |

The accumulation of mineral nitrogen can also be reduced by reducing the length of the grazing season, i.e. housing the cows at an earlier date. Especially in day-and-night grazing systems this is an effective measure to reduce $N_{min,H}$ under urine spots.

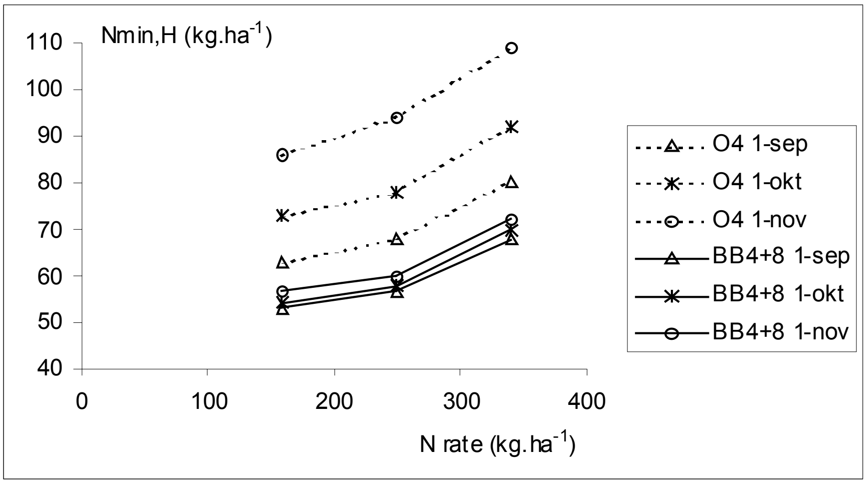


*Figure 7.7.* $N_{min,H}$ *in relation to length of grazing season, grazing system and nitrogen application.*

As shown, the intensity of grazing has a major effect on the accumulation of mineral nitrogen. The intensity of grazing can be expressed as the number of livestock unit (LU) grazing days per ha per year, in which a diary cow is equal to one LU, a heifer is equal to 0.44 LU and a calf is equal to .22 LU. Furthermore the cow grazing days are corrected for the grazing system (O = 1.0, B = 0.5 , BB = 0.25 and Z = 0). The amount of LU grazing days, together with the level of N application, has a good relationship with the accumulation of mineral N. All scenario's presented above have been brought together in Figure 7.8.

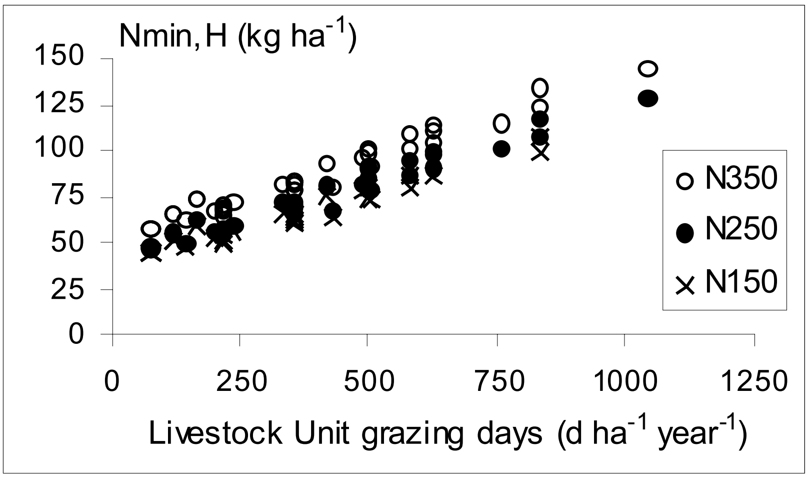


*Figure 7.8. Nmin,H in relation to intensity of grazing and N application.*

## 7.6 Relationship between paddock N surplus and mineral N.

The importance of the effect of grazing intensity on mineral N accumulation is also shown in Figure 7. The accumulation of mineral N increases with increasing N surplus. But within a similar N surplus, the accumulation of mineral N increases from zero grazing systems to day and night grazing systems. In this example the grazing system of the dairy cows have been studied. The heifers and calves have a day and night grazing system in all three systems. If heifers and calves would also be housed, the mineral N would hardly increase with increasing N surplus.

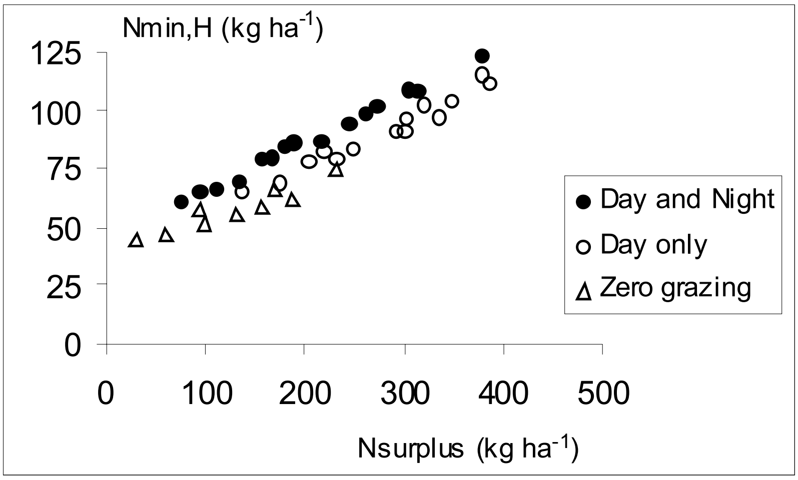


*Figure 7.9.* $N_{min,H}$ *in relation paddock N surplus, for three grazing systems.*

# 8. Nitrate leaching versus residual soil mineral nitrogen

*J. Roelsma, Alterra, P.O. Box 47, 6700 AA Wageningen*

## 8.1 Empirical relations

The amount of mineral nitrogen in the soil profile ($N_{min,H}$) has been proposed as an indicator for nitrate loading of groundwater (e.g. Prins *et al.*, 1988; Neeteson, 1994; Schröder *et al.*, 2000). Using $N_{min,H}$ for this purpose has been criticised, however, reasoning that $N_{min,H}$ is merely a snapshot with variable relationships with N management and with nitrate concentrations in groundwater (Corré, 1994a; Van Dijk, 1991). During the last decade many sources of variation have been identified, however. Moreover, alternative indicators for nitrate loss such as the difference between N-inputs and the N in produce, are probably just as much affected with variation.

Figures 8.1-8.3 demonstrate that, in these respective experiments, the over-winter nitrate concentration in the upper groundwater, and the nitrate load, was reasonably well correlated with post-harvest $N_{min,H}$. Figure 8.1 refers to experiments on cut grass during three years at Heino and five years at Ruurlo. Figures 8.2 and 8.3 compile data of Corré (1994b) (sandy soils in Haren and Jipsingboertange after maize, starch potatoes and beets) and of Schröder (1998) (sandy soils in Maarheeze, Heino and Wageningen after maize). The over-winter concentration is defined here as the flow-proportional nitrate concentration assessed with ceramic suction cups or soil sampling at a depth of circa 100 cm below the soil surface. This procedure was followed to assess nitrate leaching in all experiments underlying Figures 8.1-8.3.

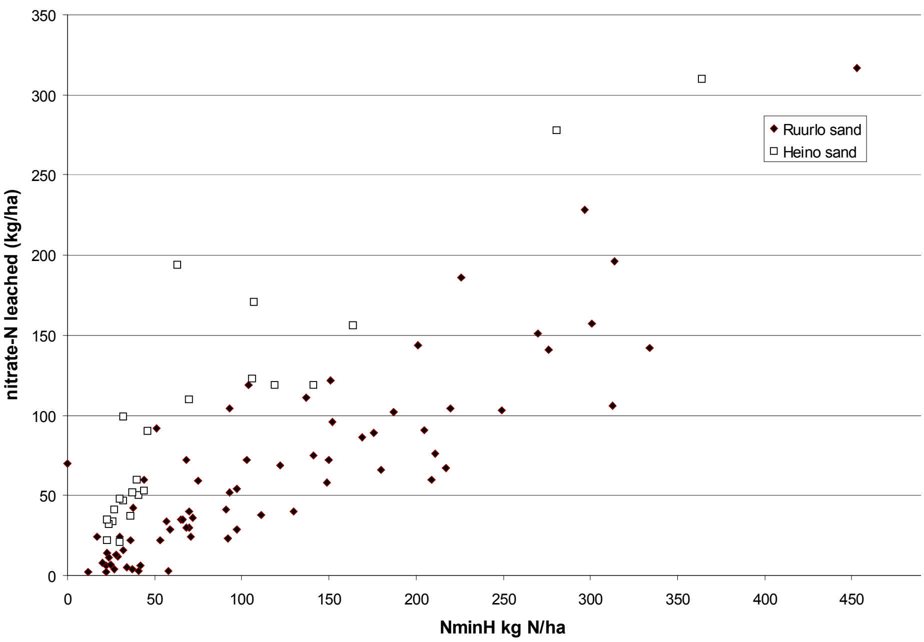


*Figure 8.1. Relation between measured residual mineral soil N at the last harvest in cut grass, and downward nitrate flux at 1 m below the soil surface. The data were collected on sandy soils at Ruurlo and Heino in the Netherlands.*

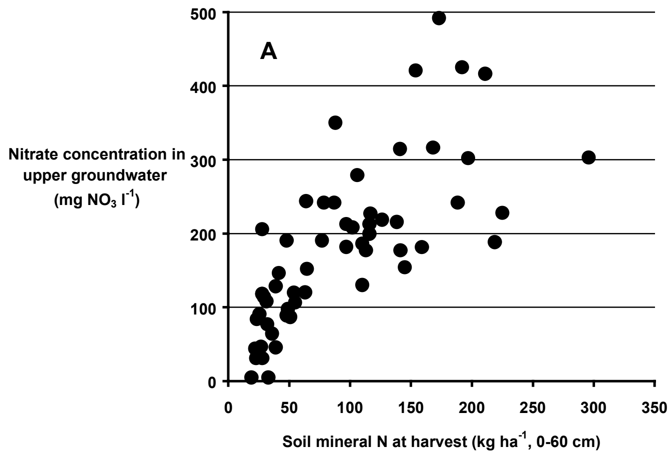


*Figure 8.2.* *Relationship between $N_{min,H}$ (soil mineral N supply at harvest, upper 60 cm) and nitrate concentration (mg $l^{-1}$) in the soil solute at 100 cm depth, in various arable crops (compiled data from five locations (Corré, 1994b; Schröder, 1998)).*

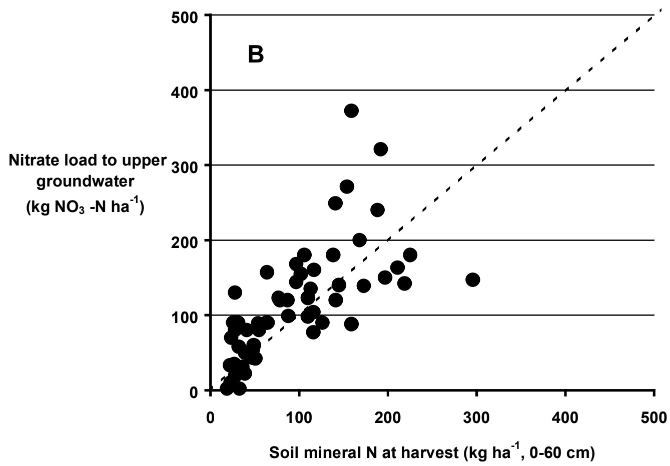


*Figure 8.3.* *Relationship between $N_{min,H}$ (soil mineral N supply at harvest, upper 60 cm) and the nitrate load (kg $ha^{-1}$) to the upper groundwater during the following winter in various arable crops (compiled data from five locations (Corré, 1994b; Schröder, 1998)).*

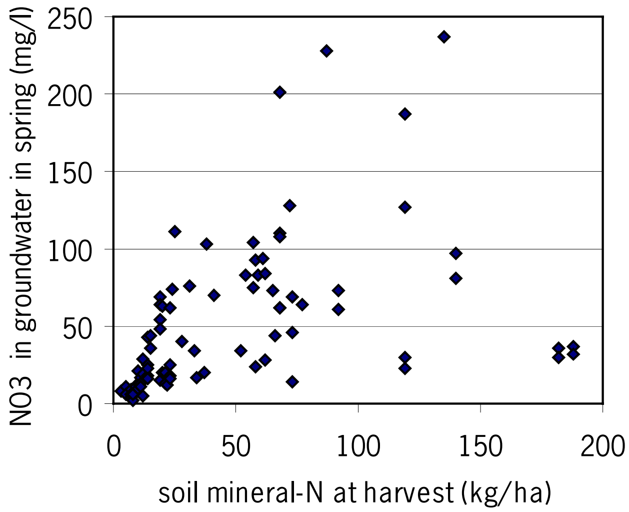


*Figure 8.4.* *Nitrate concentration in soil water (depth interval 135-150 cm) at Wijnandsrade on loess soil, versus residual mineral soil nitrogen (0-90 cm depth interval) at crop harvest. Nitrate measurements refer to early March following the respective crop seasons. Data from experiments in 1995-2000. Crop rotation: potato, winter wheat, sugarbeet, maize.*

Figure 8.4 shows the results of observations under an arable crop rotation. In contrast to Figures 8.1-8.3 (all sandy soils), this figure refers a loess soil profile, at Wijnandsrade. The experiments included a range of N-inputs, with mineral fertilisers and animal manures. (The data were included in the analyses and figures of Chapter 5.) Note that the vertical axis refers to nitrate (not nitrate-N). No clear pattern emerges, but the data suggest that the fraction of $N_{min}$ found overwinter as nitrate in deeper layers is 50 to 100%.

## 8.2 Simulation studies

This section describes a model experiment for determining the best sampling time and sampling depth of late fall residual soil mineral nitrogen and spring nitrate concentration in groundwater. The model experiment is carried out using the nutrient-leaching model ANIMO (Section 8.2.1) and four data sets which were derived from previous validation studies (Section 8.2.2).
Section 8.2.3 describes the method of determining an overall best sampling time and sampling depth of late fall residual soil mineral nitrogen and nitrate concentration in groundwater. The overall best sampling time and sampling depth is used for a synthesis with a meteorological data set of 30 and three hydrological variants (Section 8.2.4).

### 8.2.1 The nutrient leaching model ANIMO

The ANIMO model aims to quantify the relation between fertilisation level, soil management and the leaching of nutrients to groundwater and surface water systems for a wide range of soil types and different hydrological conditions (Groenendijk & Kroes, 1999; Rijtema *et al.*, 1999; Kroes & Roelsma, 1998). The model is a functional model incorporating simplified formulations of processes. The organic matter cycle plays an important role for quantifying the long-term effects of land use changes and fertilisation strategies.
Currently, the ANIMO model serves as one of the parent models for the development of the Dutch consensus leaching model STONE. STONE is regarded as the consensus nutrient emission model for all governmental departments involved in environmental policy making (National institute for health

and the environment; Institute for Inland water management and waste water treatment; Agricultural Research Department) and will operate at a national and regional scale for global problems.

#### 8.2.1.1 Carbon, nitrogen and phosphorus cycle

The simulated transformation processes are all part of the carbon and nitrogen cycle. These two cycles have been modelled according to Figures 8.5 and 8.6.
These two figures were designed in such a way that the interrelation between the cycles can be recognised. Both figures have a horizontal line which stands for both the soil surface and the top boundary of the model system. Parameters mentioned above this line indicate actions concerning additions to and removal from the soil system. Below the horizontal line the principal parameters of the soil system are shown with four kinds of organic matter in the centre of the soil system. These four kinds of organic matter are:

- fresh organic matter: root and crop residues and organic parts of manure added to the soil;
- dissolved organic matter: organic matter in solution from fresh organic matter or humus;
- exudates: dead root cells and organic products excreted by living roots;
- humus: consists of dead organic matter and of living bio mass and is formed from part of the fresh organic matter, root exudates and dissolved organic matter.

The organic material added to the soil profile varies strongly in its composition.
In the model fresh organic matter can be divided into different fractions, each with their own decomposition rate and N-content. In this way it is possible to create materials with their own specific characteristics.

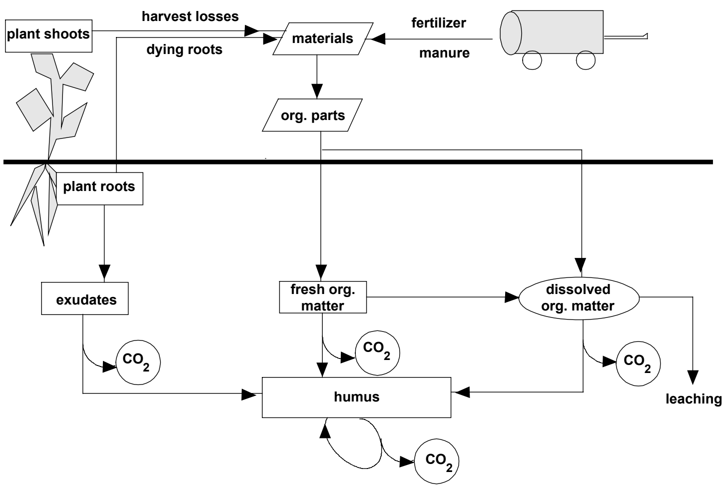


*Figure 8.5. The carbon cycle in ANIMO.*

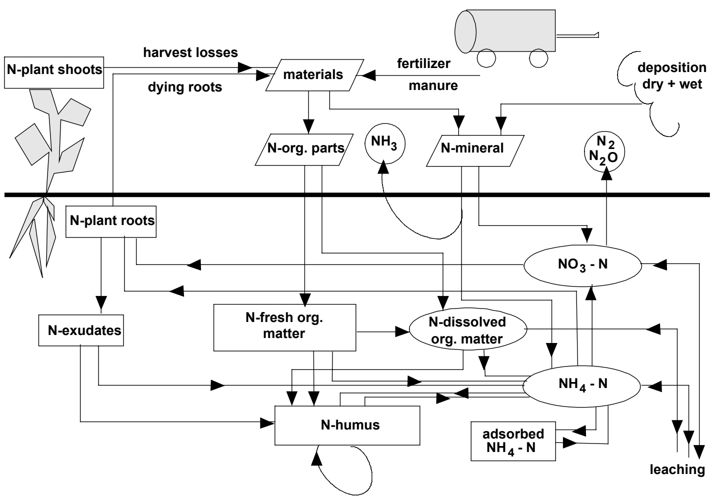


*Figure 8.6. The nitrogen cycle in ANIMO.*

In the ANIMO model the rate variables for organic matter transformation are corrected for the influences of temperature, moisture, pH and oxygen demand; the nitrification rate is corrected for influences of temperature, moisture and pH.

### 8.2.1.2 Hydrological schematisation

The ANIMO model requires data delivered by a waterquantity model (WATBAL or SWATRE). Depending on the scale of the information one of the two water quantity-models must be applied in advance. Any other model producing output like WATBAL or SWATRE can also be used. The output of one of these models must be used as input for ANIMO.
The WATBAL model produces two water balances: one for the root zone and one for the model system below the rootzone. ANIMO converts these two balances into water balances for each ANIMO-compartment. The SWATRE model produces water balances for a freely chosen amount of compartments; in ANIMO the same compartments will then be used for water quality calculations. Figure 8.7 gives a schematic representation of the water fluxes in the soil system of the model ANIMO for an arbitrary amount of compartments.
A water quantity model (e.g. SWATRE) should simulate all relevant terms of the water balance. Such a complete water balance for a soil-water-crop system can be formulated as:

$$\frac{\Delta V}{\Delta t} = q_p + q_s - q_{e,s} - q_{e,p} - q_{e,i} - q_t - q_r - q_l - q_{d,1} - q_{d,2} - q_{d,3}$$

where: $\Delta V$ is the change in areic water volume during a time step (m$^3$ m$^{-2}$), $\Delta t$ is the length of the time step (d), $q$ is a water flux (m$^3$ m$^{-2}$ d$^{-1}$) with $q_p$ is precipitation, $q_s$ is seepage, $q_{e,s}$ is the soil evaporation, $q_{e,p}$ is the ponding evaporation, $q_{e,i}$ is the interception evaporation, $q_t$ is the transpiration, $q_r$ is the surface runoff, $q_l$ is the leaching across the bottom boundary, $q_{d,1}$, $q_{d,2}$, $q_{d,3}$ is the drainage to or from (positive or negative) the first, second and third order drainage systems.

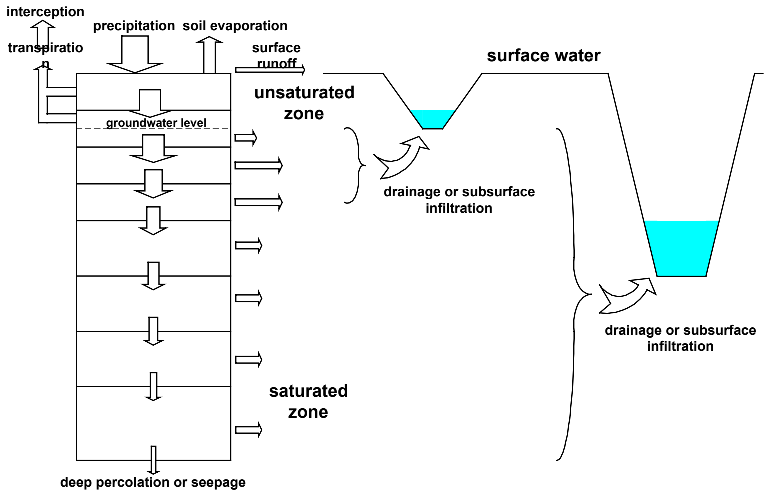


*Figure 8.7. Definition of a soil profile and the main terms of the water balance.*

#### 8.2.1.3 Transport and transformations

The substances that can be transported with water-fluxes are: $NH_4$-N, $NO_3$-N, P and the dissolved organic matter-fractions. For this transport combined with production or consumption a transport- and conservation-equation is being used (per compartment) with the general form:

$$\frac{\partial(\theta c)}{\partial t} + \rho_d \frac{\partial X_e}{\partial t} + \rho_d \frac{\partial X_n}{\partial t} + \rho_d \frac{\partial X_p}{\partial t} = -\frac{\partial}{\partial z}(qc - \theta D_{dd} \frac{\partial c}{\partial z} + R_p - R_d - R_u - R_x$$

where: $\theta$ is the volume fraction of liquid ($m^3$ $m^{-3}$), $c$ is the mass concentration in the liquid phase (kg $m^{-3}$), $t$ is time (d), $\rho_d$ is the dry bulk density (kg $m^{-3}$), $X_e$, $X_n$, $X_p$ are contents (kg $kg^{-1}$) in the solid phase of a soil, i.e. the ratio of the mass of substance at a solid phase divided by the mass of dry soil, $X_e$ is the content sorbed to the solid phase in equilibrium with $c$, $X_n$ is the content sorbed to the solid phase in non-equilibrium with $c$, $X_p$ is the precipitated content, $z$ is depth in the soil (m), $q$ is the water flux ($m^3$ $m^{-2}$ $d^{-1}$, or m $d^{-1}$), $D_{dd}$ is the apparent dispersion coefficient ($m^2$ $d^{-1}$), which is the sum of the coefficients for dispersion and diffusion of a solute in the liquid phase ($D_{dd} = D_{dis} + D_{dif}$), $R$ is a sink or source term expressed as a volumic mass rate of the substance (kg $m^{-3}$ $d^{-1}$): $R_p$ is a source for production, $R_d$ is a sink for decomposition, $R_u$ is a sink for crop uptake, $R_x$ is a sink for lateral drainage or infiltration.

This equation is solved analytically every time step for each compartment. The calculation procedure follows the flow direction in the schematic column (Figure 8.7). For the first compartment the boundary condition for the incoming flux from above is the precipitation with a concentration of the precipitation flux. For the last compartment the boundary condition of the incoming flux is the seepage flux with a concentration of the soil solution below the described profile.

The thickness of the model compartments and the length of the time step (mathematical dispersion) simulate physical dispersion. For the additions to the soil system and for the runoff to surface waters the model has an extra reservoir on top of the compartment-division. The additions can be added to this reservoir and infiltrate into the soil system with the precipitation-flux. The runoff to surface water will take place out of this reservoir. The reduction factor for crop-uptake (rd) is determined on base of the summarised crop uptake during previous time steps. For grassland the uptake includes diffusion. If the model WATBAL has been applied then the model ANIMO uses the evapotranspiration water flux instead of the transpiration flux.

### 8.2.2 Validated field studies for the ANIMO model

With the nitrogen and phosphorus leaching model ANIMO simulations were carried out using data sets from previous validation studies. Two of these validation studies were carried out on permanent grassland fields, one on a maize field and one on a rotation scheme of maize, sugar beet and potato (Groenendijk & Kroes, 1999; Kroes & Roelsma, 2001; Jansen, 1991a; Jansen 1991b).
In Table 8.1 some general information on the four validation sites is presented.

*Table 8.1. General characteristics of the validation sites.*

| Name site | Land use | Simulation period | Soil type | GWT |
|---|---|---|---|---|
| Cranendonck 1 | grassland | 1992 - 1999 | Fimic Anthrosol | VII |
| Ruurlo | grassland | 1980 - 1984 | Gleyic Podzol | V* |
| Cranendonck 2 | maize | 1974 - 1982 | Fimic Anthrosol | VII |
| Vredepeel | maize, sugar beet, potato | 1990-1995 | Gleyic Podzol | VII |

In Figures 8.8 and 8.9 the measured and simulated ammonium and nitrate concentrations for the soil layers 0-5 cm, 5-10 cm, 10-20 cm and 20-30 cm for the Cranendonck field experiment data are presented. The simulated ammonium and nitrate concentrations show a fairly good comparison between simulated and measured values.
Figure 8.10 shows the measured and simulated mineral nitrogen content in 0-50 cm below soil surface, the nitrate concentration at 1 meter below soil surface and the uptake of nitrogen by grassland for the Ruurlo field experiment data. Results of the validation on the Ruurlo data set generally exhibit a good agreement between simulated and measured values.

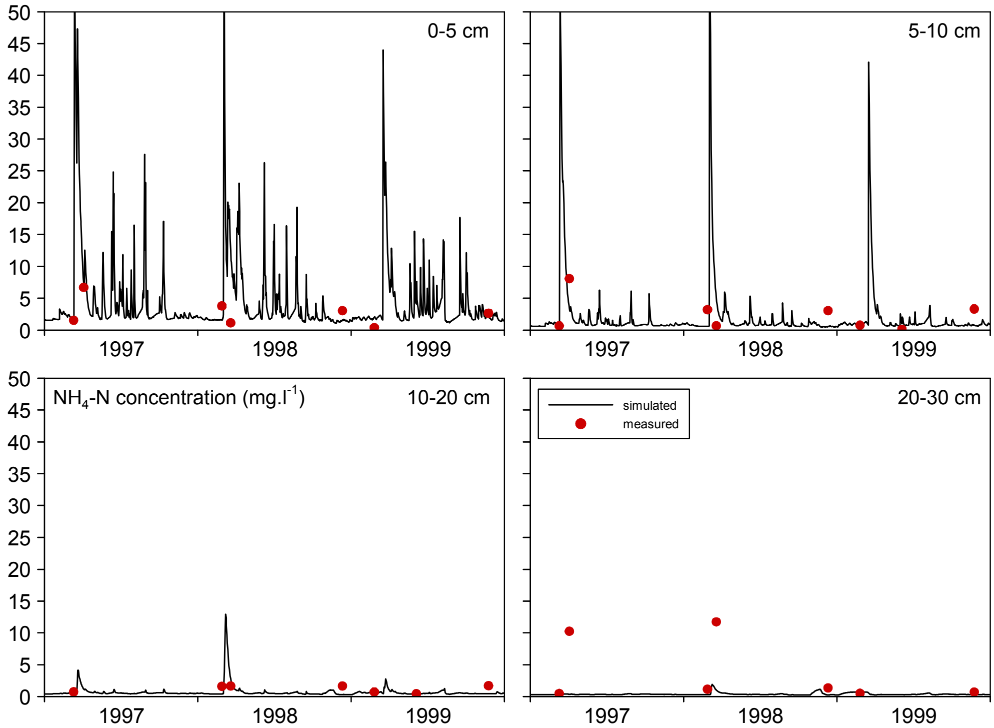


*Figure 8.8. Validation on Cranendonck field experiment data: measured and simulated $NH_4$-N concentrations at 4 different soil layers for permanent grassland.*

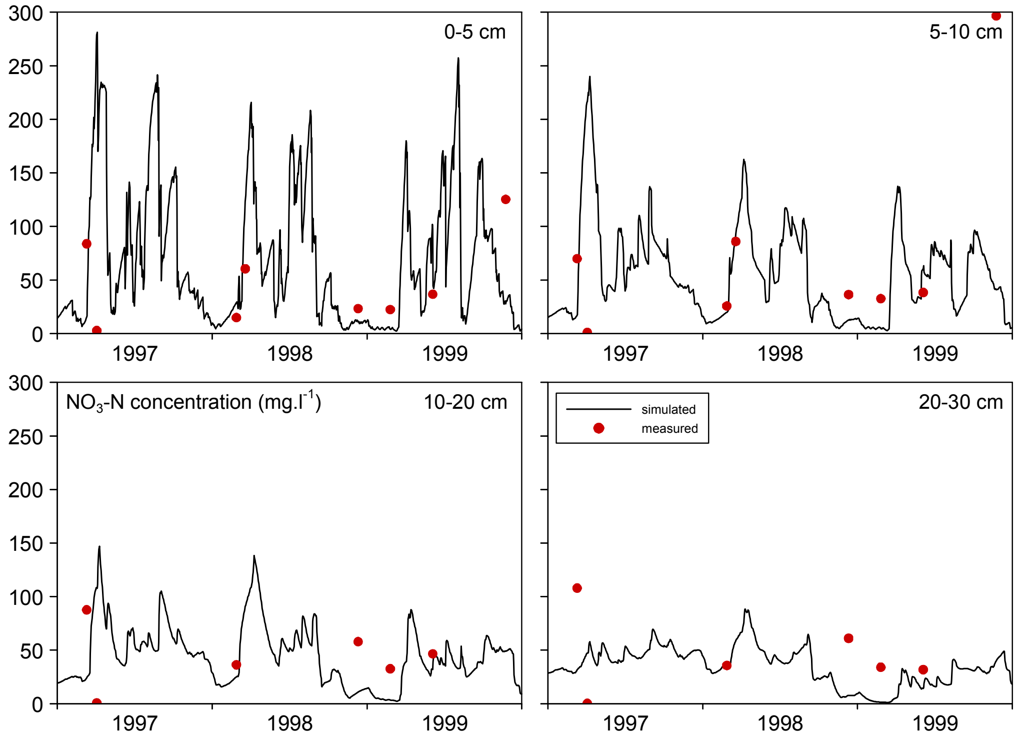


*Figure 8.9. Validation on Cranendonck field experiment data: simulated and measured $NO_3$-N concentrations at 4 different soil layers for permanent grassland.*

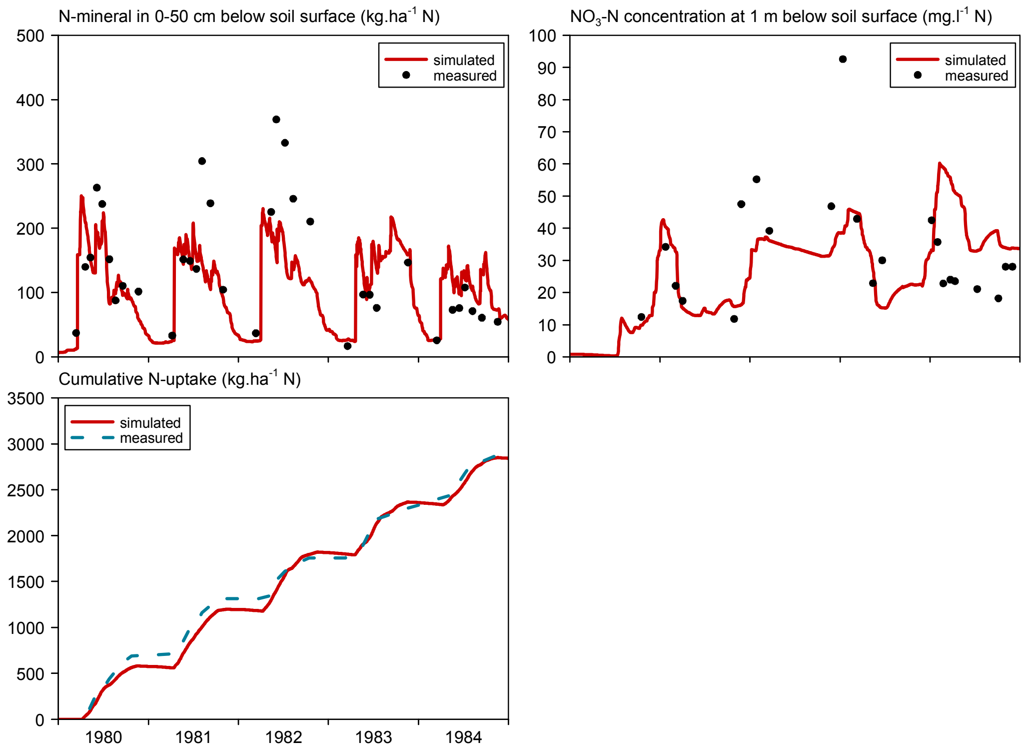


*Figure 8.10. Validation on Ruurlo field experiment data: simulated and measured mineral nitrogen content, $NO_3$-N concentration at 1 m below soil surface and uptake of nitrogen by crop for permanent grassland.*

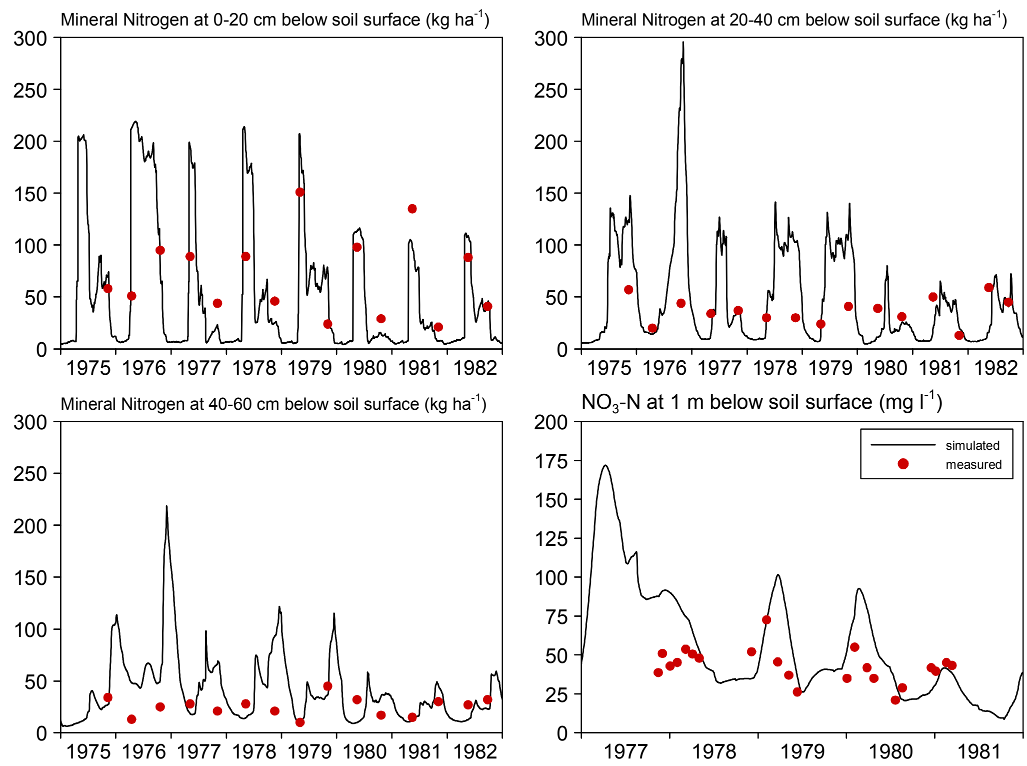


*Figure 8.11. Validation on Cranendonck field experiment data: simulated and measured mineral nitrogen content for 3 different soil layers and $NO_3$-N concentrations at 1 m below soil surface for maize*

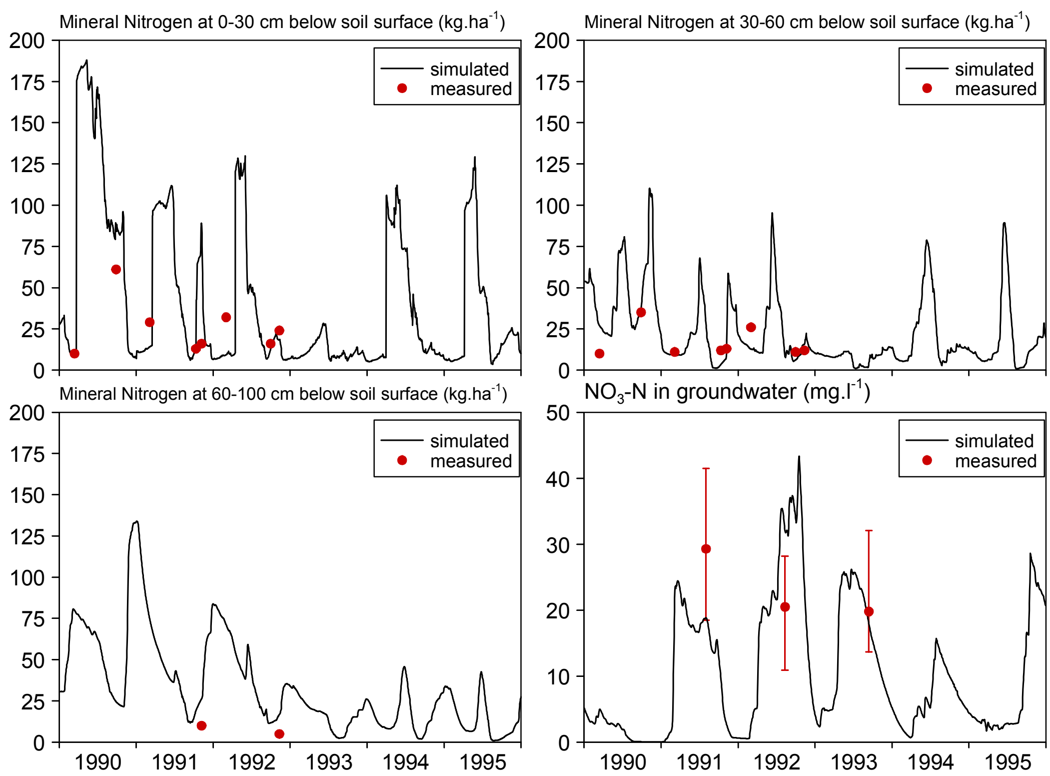


*Figure 8.12. Validation on Vredepeel field experiment data: simulated and measured mineral nitrogen content for 3 different soil layers and $NO_3$-N concentrations in groundwater for arable crops.*

In Figure 8.11 the measured and simulated mineral nitrogen content for the soil layers 0-20 cm, 20-40 cm and 40-60 cm and nitrate concentration at 1 meter below soil surface for the Cranendonck field experiment data are presented. For this data set results also generally exhibit a good agreement between simulated and measured values. In Figure 8.12 the simulation results of the ANIMO model for the rotation scheme of Vredepeel are depicted. Simulated mineral nitrogen values are in good agreement with the measured values. Measured values are in between simulated peak periods of mineral nitrogen. An explanation herefore is the date of monitoring. The period of sample taking for mineral nitrogen is before fertilization and after harvesting. Simulated nitrate concentrations shows a fairly good comparison between simulated and measured values.
To create a range in the calculated residual soil mineral nitrogen the validation sites are simulated using a range in application of mineral fertiliser and manure. The addition ranges used were: 50 - 300 kg $ha^{-1}$ N for maize and from 50 - 400 kg $ha^{-1}$ N for grassland each with addition steps of 50 kg.$ha^{-1}$ N. This means that for grassland 8 simulations were carried out, while for maize 6 simulations were carried out. For the Vredepeel field experiment the data set has been changed from a rotation scheme of arable crops into permanent maize.

### 8.2.3 Searching the best sampling time and sampling depth

The ANIMO model generates time series of output for each model compartment (Figure 8.13). After each simulation the output data of residual soil mineral nitrogen were ‘collected’ on a specific time interval and soil depths. The time interval used for late fall residual soil mineral nitrogen was: 1 October - 26 December using time steps of five days. For grassland the depths of ‘collecting’ of residual soil mineral nitrogen were: 0-30 cm below soil surface, 30-60 cm below soil surface and 60-100 cm below soil surface. For maize the soil depths were: 0-30 cm below soil surface and 30-60 cm below soil surface.

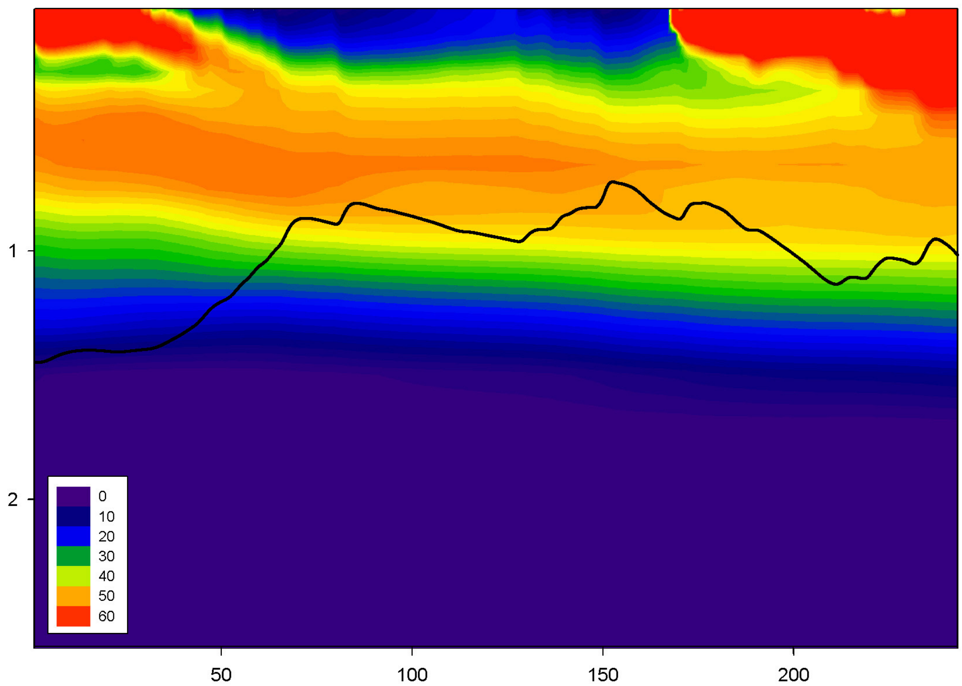


*Figure 8.13. Example of calculated nitrate concentrations in the soil profile (vertical axis: 0-250 cm below soil surface) from 1 October 1996 (daynr. 1) till 31 May 1997 (daynr. 243) (time on horizontal axis). Bright red areas refer to fertiliser applications.*

These 'samples' of late fall residual soil mineral nitrogen were combined with the output data of nitrate concentrations in groundwater. The data of nitrate concentrations were collected on a specific time interval and groundwater depths also. The time interval used for spring nitrate concentration in groundwater was 1 January - 26 June using time steps of five days. The depths of the groundwater sampling used were: the upper meter of the groundwater, the upper 20 cm of groundwater, the layer of 20-40 cm below groundwater level, the layer of 40-60 cm below groundwater level, the layer of 60-80 cm below groundwater level and the layer of 80-100 cm below groundwater level. For this output data a correlation coefficient has been calculated for each combination of late fall residual soil mineral nitrogen and spring nitrate concentration in time and depth using linear regression. In Table 8.2 and Figure 8.14 the results for the best fit between late fall residual soil mineral nitrogen and spring nitrate concentration in groundwater for the four validation sites are presented.

*Table 8.2. Best fit between late fall residual soil mineral nitrogen and spring nitrate concentration in groundwater for the three validation sites.*

| Name site | Time SMN | Depth SMN | Time $NO_3$ | Depth $NO_3$ | $R^2$ |
|---|---|---|---|---|---|
| Cranendonck grassland | 1 Dec | 60-100 cm | 1 Apr | upper meter | 0.96 |
| Ruurlo grassland | 26 Dec | 0-100 cm | 21 Jan | upper meter | 0.97 |
| Cranendonck maize | 16 Nov | 30-60 cm | 16 May | upper 20 cm | 0.87 |
| Vredepeel maize | 11 Nov | 0-30 | 11 Mar | upper 20 cm | 0.86 |

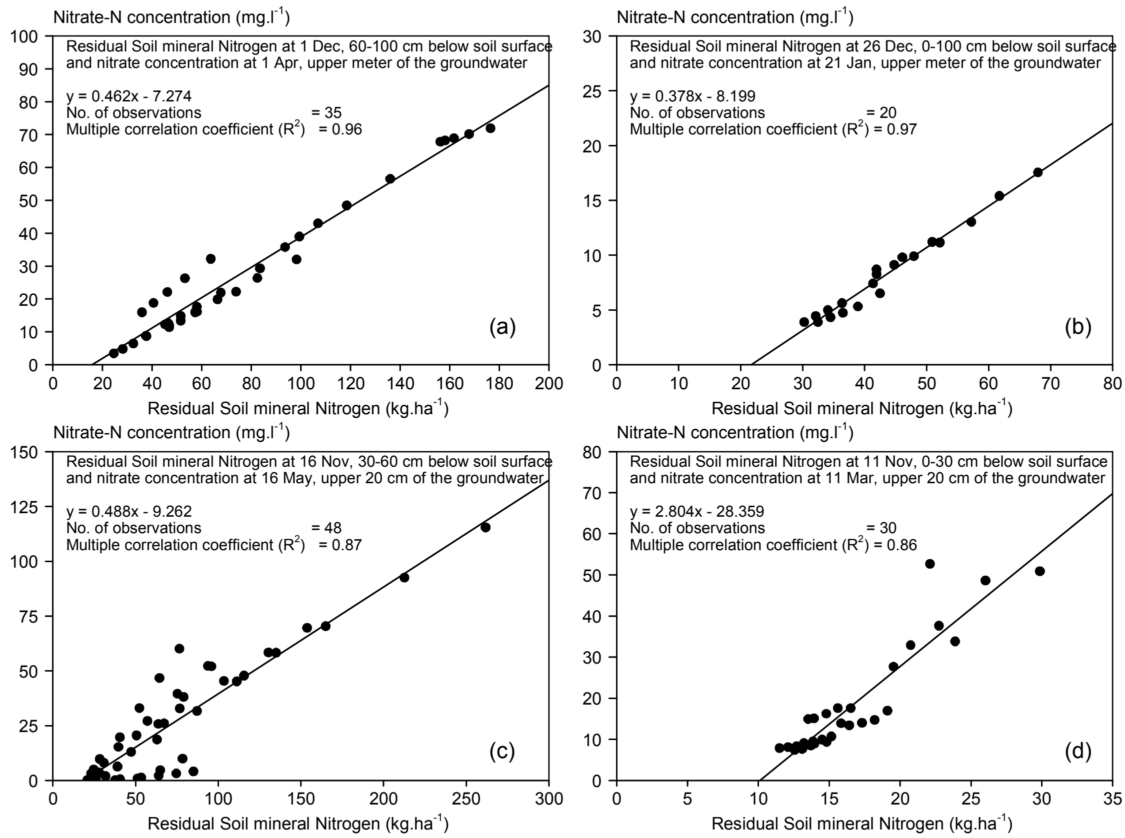


*Figure 8.14. Best fit between late fall residual soil mineral nitrogen and spring nitrate concentration in groundwater for Cranendonck grassland (a), Ruurlo grassland (b), Cranendonck maize (c) and Vredepeel maize (d).*

In Appendix III the results of the correlation between different times and depths of residual soil mineral nitrogen and nitrate in groundwater are presented.
Based on this simulation experiment and on empirical data (Section 8.1) the sample time of 1 December for late fall residual soil mineral nitrogen and 1 April of the next year for nitrate concentration in groundwater has been chosen. For grassland the sample depth of 0-100 cm below soil surface and for maize the sample depth of 0-60 cm below soil surface gives the best overall fit between residual soil mineral nitrogen and nitrate concentration in the upper meter of the groundwater. In Table 8.3 and Figure 8.15 the fit between residual soil mineral nitrogen and nitrate concentration in the groundwater for these sampling time and sampling depth are presented.

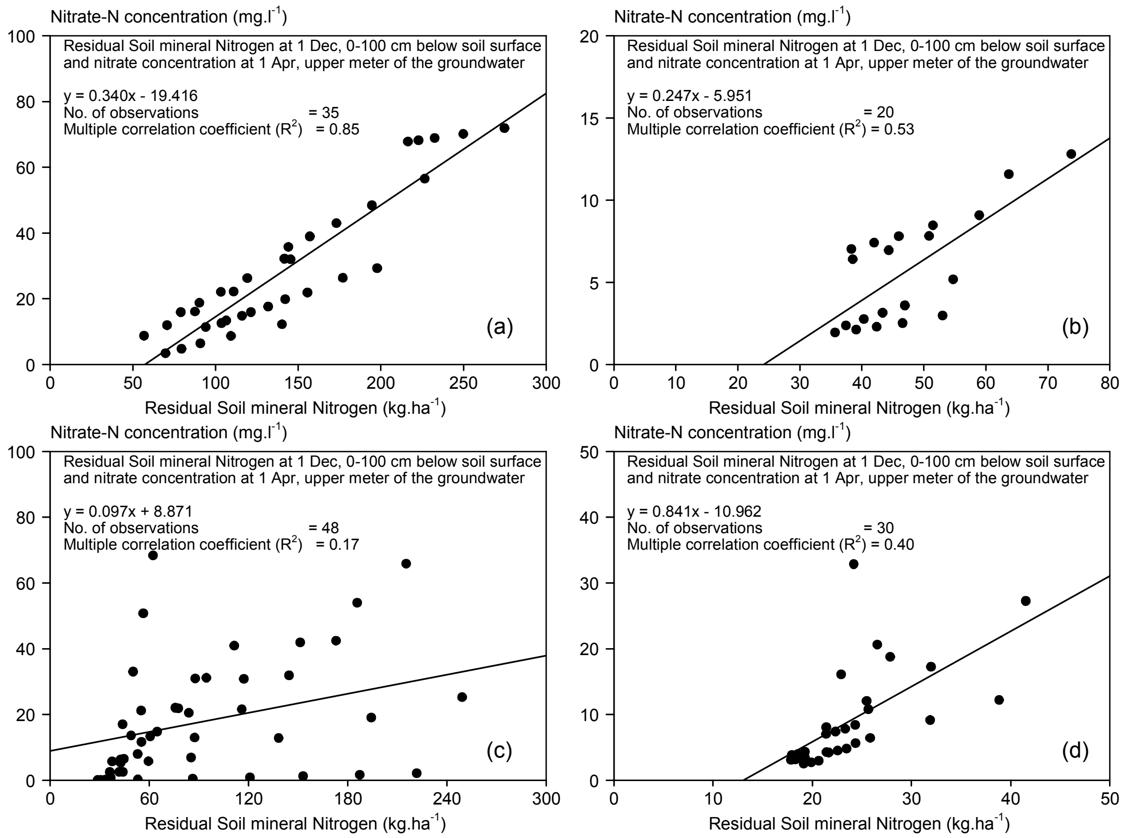


*Figure 8.15. Fit between residual soil mineral nitrogen at 1 December at soil layer 0-100 cm and nitrate concentration at 1 April in the upper meter of the groundwater for Cranendonck grassland (a), Ruurlo grassland (b), Cranendonck maize (c) and Vredepeel maize (d).*

The fits for the overall sampling time and depths show poor results for the Ruurlo grassland and Crandendonck maize data set. This indicates that the relation between late fall residual soil mineral nitrogen and spring nitrate concentration in groundwater is very sensitive for changes in sample time and depth for residual soil mineral nitrogen and nitrate in groundwater.
The relation between late fall residual soil mineral nitrogen and nitrate flux at 1 meter below soil surface for the period 1 October - 1 April shows some better results for the data set for Ruurlo grassland and Cranendonck maize (respectively $R^2$=0.89 and $R^2$=0.39). However, for the data set for Cranendonck grassland the correlation coefficient decreases from $R^2$=0.85 to $R^2$=0.64.

*Table 8.3. Fit between late fall residual soil mineral nitrogen and spring nitrate concentration in groundwater for the three validation sites.*

| Name site | Time SMN | Depth SMN | Time $NO_3$ | Depth $NO_3$ | $R^2$ |
|---|---|---|---|---|---|
| Cranendonck grassland | 1 Dec | 0-100 cm | 1 Apr | upper meter | 0.85 |
| Ruurlo grassland | 1 Dec | 0-100 cm | 1 Apr | upper meter | 0.53 |
| Cranendonck maize | 1 Dec | 0-60 cm | 1 Apr | upper meter | 0.17 |
| Vredepeel maize | 1 Dec | 0-60 cm | 1 Apr | upper meter | 0.40 |

### 8.2.4 Generation and analysis of synthetic data on $N_{min,H}$ and groundwater nitrate

The four crop-soil systems parameterised in the earlier validation studies (Ruurlo grass; Cranendonck grass; Cranendonck maize and Vredepeel maize) were used to generate time series of $N_{min,H}$ and groundwater nitrate concentration. The same N rates as in paragraph 8.2.2 were imposed, and a meteorological data set was used with daily weather data from 1970 to 1999 originating from Eindhoven weather station in the Netherlands (Interreg set). For each of the four cases, we imposed in addition to the reference (groundwater) hydrology also a variant with a deeper groundwater tables (dry variant) and one with a shallower groundwater tables (wet variant). For each of these variants, the correlation coefficient between the late fall residual soil mineral nitrogen and spring nitrate concentration in groundwater (sample time and sample depth as in Section 8.2.3.) was determined, using for each case the output for the 30 simulated years. The results of the linear regression are presented in Table 8.4 and Appendix IV.

*Table 8.4. Relationship between residual soil mineral nitrogen on 1 December at 0-100 cm below soil surface (grassland) or at 0-60 cm below soil surface (maize) and nitrate-N concentration on 1 April in the upper meter of the groundwater.*

| Name site | GWT | Variant | $R^2$ | Relation |
|---|---|---|---|---|
| Cranendonck grassland | VII | reference | 0.4893 | Y = 0.229*X - 4.144 |
| | IV | wet | 0.5759 | Y = 0.182*X - 3.817 |
| | VIII | dry | 0.0726 | Y = 0.125*X - 3.866 |
| Ruurlo grassland | V* | reference | 0.3544 | Y = 0.114*X - 1.032 |
| | III | wet | 0.0766 | Y = 0.080*X - 0.380 |
| | VIII | dry | 0.0380 | Y = 0.076*X + 12.627 |
| Cranendonck maize | VII | reference | 0.1728 | Y = 0.578*X + 18.648 |
| | IV | wet | 0.3836 | Y = 0.449*X + 0.260 |
| | VIII | dry | 0.0594 | Y = 0.440*X + 30.234 |
| Vredepeel maize | VII | reference | 0.1040 | Y = 0.179*X + 2.539 |
| | IV | wet | 0.6131 | Y = 0.234*X - 3.589 |
| | VIII | dry | 0.0063 | Y = 0.044*X + 7.611 |

In general the calculated correlation coefficient using the 30 years meteorological data set decreases in comparison to the calculated correlation coefficient using the validation data sets. This indicates that the weather conditions have a strong influence on the relation between late fall residual soil mineral nitrogen and spring nitrate concentration in groundwater. Furthermore, an overall improvement in the calculated correlation coefficient for the wet variant can be seen. For all four data sets the calculated correlation for the dry variant is less than 0.10.

To explore the influence of the weather conditions on the relationship between residual soil mineral nitrogen and nitrate concentration in groundwater some extra calculations have been made using the precipitation surplus and the groundwater level as an additional predictor. In Table 8.5 the results of the linear regression using precipitation surplus for the period 1 December till 1 April as an additional predictor are presented. In Table 8.6 the results of the linear regression using the groundwater level at 1 April as an additional predictor are depicted. In both cases the correlation coefficient improves strongly. This indicates that both precipitation surplus and groundwater level are good predictors for the influence of the weather conditions with respect to nitrate leaching.

*Table 8.5. Relationship between residual soil mineral nitrogen on 1 December at 0-100 cm below soil surface (grassland) or at 0-60 cm below soil surface (maize) and nitrate-N concentration on 1 April in the upper meter of the groundwater with precipitation surplus for the period 1 December till 1 April (Q) as additional predictor.*

| Name site | GWT | Variant | $R^2$ | Relation |
|---|---|---|---|---|
| Cranendonck grassland | VII | reference | 0.7090 | Y = 0.229*X + 0.083*Q - 16.718 |
| | IV | wet | 0.8273 | Y = 0.178*X + 0.040*Q - 10.813 |
| | VIII | dry | 0.7091 | Y = 0.131*X + 0.112*Q - 16.644 |
| Ruurlo grassland | V* | reference | 0.3892 | Y = 0.123*X + 0.005*Q - 2.242 |
| | III | wet | 0.1705 | Y = 0.085*X + 0.011*Q - 2.011 |
| | VIII | dry | 0.1913 | Y = 0.098*X + 0.039*Q + 3.899 |
| Cranendonck maize | VII | reference | 0.1803 | Y = 0.593*X + 0.045*Q + 9.043 |
| | IV | wet | 0.3841 | Y = 0.447*X + 0.008*Q + 1.882 |
| | VIII | dry | 0.1263 | Y = 0.494*X + 0.144*Q - 0.430 |
| Vredepeel maize | VII | reference | 0.2294 | Y = 0.199*X + 0.045*Q - 5.987 |
| | IV | wet | 0.6665 | Y = 0.253*X + 0.031*Q - 9.478 |
| | VIII | dry | 0.2714 | Y = 0.083*X + 0.052*Q - 3.240 |

*Table 8.6. Relationship between residual soil mineral nitrogen on 1 December at 0-100 cm below soil surface (grassland) or at 0-60 cm below soil surface (maize) and nitrate-N concentration on 1 April in the upper meter of the groundwater with groundwater level at 1 April (Q) as additional predictor.*

| Name site | GWT | Variant | $R^2$ | Relation |
|---|---|---|---|---|
| Cranendonck grassland | VII | reference | 0.6596 | Y = 0.214*X + 0.096*Q + 2.636 |
| | IV | wet | 0.7985 | Y = 0.166*X + 0.184*Q + 10.231 |
| | VIII | dry | 0.8000 | Y = 0.173*X + 0.276*Q + 44.461 |
| Ruurlo grassland | V* | reference | 0.4658 | Y = 0.123*X + 0.027*Q + 0.234 |
| | III | wet | 0.7304 | Y = 0.070*X + 0.050*Q + 1.839 |
| | VIII | dry | 0.2242 | Y = 0.130*X + 1.383*Q + 36.685 |
| Cranendonck maize | VII | reference | 0.1949 | Y = 0.612*X + 0.326*Q + 49.748 |
| | IV | wet | 0.3952 | Y = 0.470*X + 0.222*Q + 13.883 |
| | VIII | dry | 0.1405 | Y = 0.603*X + 0.366*Q + 78.724 |
| Vredepeel maize | VII | reference | 0.2879 | Y = 0.231*X + 0.198*Q + 21.380 |
| | IV | wet | 0.6559 | Y = 0.244*X + 0.072*Q + 0.266 |
| | VIII | dry | 0.3201 | Y = 0.131*X + 0.249*Q + 48.479 |

# 9. Relations between farm N-surplus and other indicators for nitrate loss: arable systems

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## 9.1 Introduction

This chapter presents the relationship between the N-surplus at the farm level and the indicators: N-surplus at the field level; soil mineral nitrogen at harvest and; soil mineral nitrogen on December first. Calculations were made with a set of 24 representative farm types in which mineral fertilisers and manure are used according to good agricultural practice.

## 9.2 Methods

### 9.2.1 Calculation of the indicators

To enable comparison between the N-surplus at the farm level and the other indicators, the latter was converted to the farm level. In this respect, a farm was considered as the sum of the individual parcels.

When the residual soil mineral-N at harvest and late fall is regarded as a potential for nitrogen leaching, often reference is made to the soil layer of 0-100 cm. For that purpose, the mineral-N values of 0-60 cm as estimated in chapter 5 for each crop, were multiplied with 1,4 according to Wadman *et al.* (1989) and Postma & Van Erp (1998). The residual mineral-N on December first was determined for each crop as discussed in chapter 6.

Distinction was made between the N-surplus according to the Minas regulation and the total farm level surplus. The Minas surplus for nitrogen was calculated as follows:

*Minas-surplus = N-input (organic fertiliser + mineral fertiliser + fixation) – standard N-output*

The N-input comprises the total amount of fertiliser-N applied at the farm level within one administrative year divided by the total number of hectares occupied. From 2002 onwards, N-fixation by leguminous crops will be included in Minas as well. For dwarf French bean and garden pea, N-fixation will be set at 30 and 50 kg N/ha. The standard N-output is fixed at 165 kg N/ha per year irrespectively to the type of crop and yield[#].

A farmer will be charged when the Minas-surplus exceeds a given critical value. This critical value will gradually lower to 60 and 100 kg N/ha per year for respectively well drained sandy and loess soils and other types of soils. For arable farming, these values will probably be operational from 2003 onwards.

The total farm level N-surplus was calculated as follows:

*Total N-surplus = N-input (organic fert. + mineral fert. + fixation + deposition) – real N-output*

In this balance the atmospheric N-deposition was taken into account as well. N-deposition was averaged at 30 kg N/ha per year for the sandy soils in the Northeast and the loess soils in the South. For the Southeast this was 44 kg N/ha due to the higher density of dairy farms. The real N-output was calculated with the average yields and the standard N-contents of the produce (PAV, 2000; IKC, 1996).

[#] Excluded are fodder crops like silage maize. For silage maize the N-output is calculated by multiplying the obtained yield with its standard N-content of 4,3 kg N/ton. At an average yield of 37,5 ton/ha the output will be 161 kg N. The little difference with 165 kg N/ha has not been taken into account in this study.

### 9.2.2 Composition of the farms

Use was made of a set of farm types that represents the current situation on sandy and loess soils in the Netherlands and that has enough variation in crop rotation to investigate the relation between N-surplus at the field level and the other indicators (Van Dijk & Van Der Schoot, 1999).

**Arable farms**

- Crop rotations were considered for the following area's: sandy soils of Southeast Netherlands (SEN), sandy soils of Northeast Netherlands (NEN) and the loess in the South (Table 9.1).
- Cereals, sugar beet and potatoes constituted mayor part of all crop rotations. According to practice, straw from wheat, rye and barley was removed from the field for sale.
- Some rotations included horticultural crops with a large difference in N-demand.

*Table 9.1. Selected arable farms on sand and loess.*

| Area | Percentage of the crop in rotation | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | winter wheat | summ.barley | rye | silage maize | sugar beet | ware potato | starch potato | fine carrot | broc-coli | cauli-flower | leek[#] | witloof chicory | wintercarrot | garden pea[$] and dwarf French bean |
| SEN | 15 | 10 | | | 20 | 25 | | | | | | | 15 | 15 |
| | 15 | 10 | | | 20 | 25 | | | | | 15 | | 15 | |
| | | | | 25 | 20 | 25 | | | | | | | 15 | 15 |
| | | | | 25 | 20 | 25 | | | | | 15 | | 15 | |
| NEN | 8 | 15 | 7 | | 20 | | 50 | | | | | | | |
| | 13 | 25 | 12 | | 20 | | 30 | | | | | | | |
| | 10 | 20 | 10 | | 20 | | 30 | 10 | | | | | | |
| | 10 | 20 | 10 | | 20 | | 30 | | 10 | | | | | |
| Loess | 56 | 14 | | | 30 | | | | | | | | | |
| | 45 | 10 | | | 20 | 25 | | | | | | | | |
| | 35 | 10 | | | 20 | 25 | | | | | | 10 | | |
| | 35 | 10 | | | 20 | 25 | | | | 10 | | | | |

[#] *Considering an equal distribution of three cultivation periods: early autumn, late autumn, and early winter.*
[$] *Garden pea followed by dwarf French bean in the same season.*

The area-specific considerations were as follows:
Sandy soils in the Southeast

- Rotations included ware potatoes and 30% horticultural crops because many arable farms in this area cultivate horticultural crops as well.
- Two farm types contained silage maize instead of wheat and barley since maize is commonly grown in this area.

Sandy soils in the Northeast

- Rotations containing 50% and 30% starch potatoes, with and without horticultural crops.

Loess soils

- Rotations with and without ware potatoes and horticultural crops that are common in this area.

**Horticultural farms**

- Since most specialised horticultural farms on sandy soils are situated in Southeast Netherlands, crop rotations from this area were considered only (Table 9.2).
- Calculations were made with specialised farms cultivating leek, iceberg lettuce, strawberry or fine carrots. Rotations were included having different combinations of the mentioned crops and Chinese cabbage.
- Combinations of lettuce-strawberry and strawberry-carrot were excluded since it causes an unfavourable distribution of labour demand.
- Iceberg lettuce, Chinese cabbage and fine carrots were cultivated twice per season.

*Table 9.2. Selected horticultural farms on sandy soils in the Southeast of the Netherlands.*

| Type of farm | Percentage of the crop in rotation | | | | |
|---|---|---|---|---|---|
| | leek | iceberg lettuce | strawberry | fine carrots | Chinese cabbage |
| leek farms | 100 | | | | |
| | 70 | 30 | | | |
| | 70 | | 30 | | |
| | 70 | | | 15 | 15 |
| | 33 | | 33 | | 33 |
| iceberg lettuce farms | | 100 | | | |
| | | 70 | | 15 | 15 |
| | 50 | 50 | | | |
| | 33 | 33 | | 16 | 16 |
| | 33 | 33 | | | 33 |
| strawberry farms | | | 100 | | |
| carrot farms | | | | 100 | |

## 9.2.3 Fertiliser use

- Fertiliser rates were used according to the recommendations (Van Dijk, 1999).
- The use of techniques to improve the efficiency of fertilisers (like NBS, etc) was excluded.
- When two crops are cultivated in the same season (lettuce, fine carrots and Chinese cabbage), the second crop received half of the recommended N-rate for the first crop.
- The recommended N-rate for crops followed by sugar beet, broccoli or cauliflower was reduced by 30 kg N/ha because the residues of these crops contribute to the N- supply through mineralisation.
- The soil mineral nitrogen in spring was set at an average of 20, 30 and 40 kg N/ha in the soil layers 0-30, 0-60 en 0-90 cm respectively.

Considerations regarding the use of organic fertilisers were:

- Application of pig slurry (most used in sandy soils) in spring through injection according to good agricultural practice.
- Effective N-rate of the manure was calculated according to the recommendations (Van Dijk, 1999) and subtracted from the mineral fertiliser rates.
- The manure was applied to potatoes, silage maize (both with 30 $m^3$/ha), dwarf French beans, cauliflower, broccoli (25 $m^3$/ha), sugar beet, leek, iceberg lettuce and Chinese cabbage (20 $m^3$/ha). In a few cases the amount of manure was a bit reduced to remain below the critical level of Minas-surplus for organic phosphorus.

# 9.3 Results

## 9.3.1 Relating Minas-surplus to total N-surplus at the farm level

Figure 9.1 shows an almost 1:1 linear relation between both indicators. Minas-surplus is on average about 90 kg N/ha less than the total N-surplus at the farm level. This gap is a result of the N-deposition (30 – 44 kg/ha) and the difference between the fixed N-output according to Minas and the real N-output through the harvested products. The difference among crops in output (see 9.3.2) is the source of variation in this relation. This is very evident for the specialised strawberry and fine carrot farms.

The relation is not affected by application of animal manure since it affects both indicators equally. The figure also indicates that specialised horticultural farms in general are more liable to exceed the critical Minas-surplus of 60 kg N/ha than arable farms. The high Minas and total farm N-surplus predicted in horticultural farms (except those specialised in fine carrots and strawberries) is caused by the high N-demand of many horticultural crops, double cropping for crops with a short growing cycle and the low N-output of many crops (see 9.3.2).

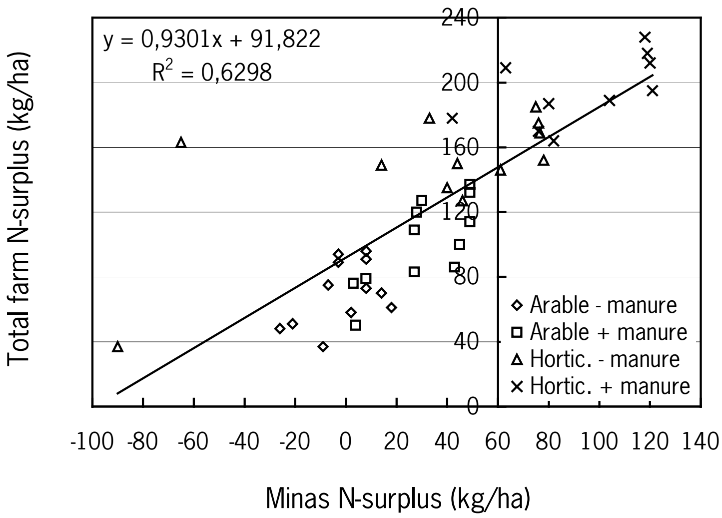


*Figure 9.1. Relation between Minas and total N-surplus for farms growing arable crops and field vegetables on sandy and loess soils.*

### 9.3.2 Relating total N-surplus at the farm level to the field level

The total farm surplus is the average of the surpluses at the parcel level, taking into account the area of the individual parcels. Figure 9.2 shows the N-demand of the individual crops according to the fertiliser recommendations together with the N-output though harvest. Crops differ considerably in fertiliser need in order to get optimal production and quality. Factors that play a major role are: the growing period, rooting depth and stage of the growing cycle at harvest. When two or three crops are grown in the same season (as for leafy vegetables and broccoli) the Minas-surplus increases. Each crop is fertilised separately while the Minas-output remains 165 kg N/ha per year. For sugar beet and most cabbages the situation will be slightly better than the figure suggests, since their crop residues will contribute to the N-supply through mineralisation in the following growing season (see 9.2.3).

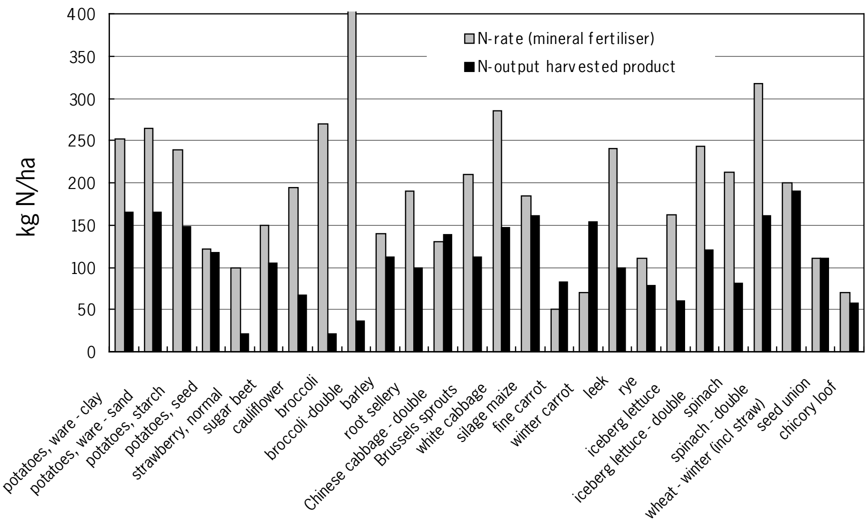


*Figure 9.2. Recommended N-rates and predicted N-output for major arable crops and field vegetables under average conditions.*

Crops differ also much in N-output through the harvested products. For broccoli and strawberry this is about 20 kg N/ha only. For crops such as potatoes, white cabbage, silage maize and winter wheat N-output is 7 to 8 times as high. Figure 9.2 illustrates also the poor relation between N-output and N-demand among the crops.

As a result, the total N-surplus at the parcel level will provide little information on the total surplus at the farm level without proper knowledge regarding the crop rotation.

### 9.3.3 Relating Minas-surplus to soil mineral-N at harvest

Figure 9.3 shows a rather weak relation between both indicators. The indicators are only indirectly related and factors causing the variation are many. As mentioned in 9.3.1, Minas N-surplus is only a rough estimate of the real N-surplus. Other sources of variation are the variate ability of crops to absorb nitrogen and the application of manure (see 9.3.4).

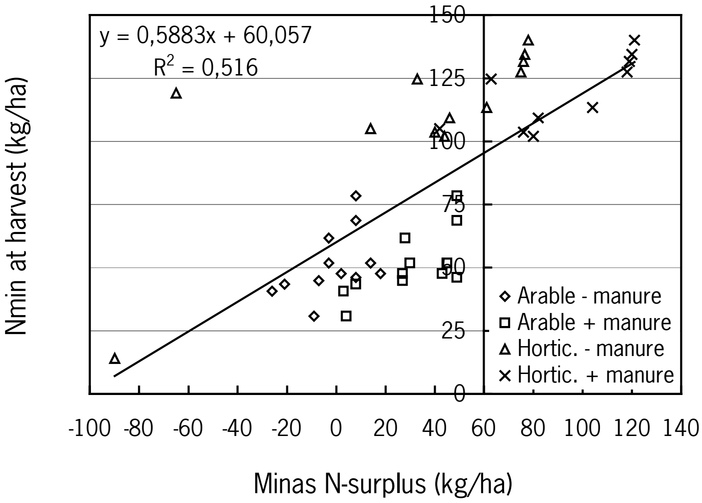


*Figure 9.3. Relation between Minas surplus and residual soil mineral-N at harvest (0-100 cm) for farms growing arable crops and field vegetables on sandy and loess soils.*

## 9.3.4 Relating total farm N-surplus to soil mineral-N at harvest

The total farm surplus is better related to the residual soil mineral-N at harvest than the Minas N-surplus (Figures 9.4 and 9.3). These relations have a correlation coefficient ($R^2$) of 0.84 and 0,52 respectively. On sandy and loess soils about 65% of the real farm N-surplus was found as residual soil mineral-N. For sandy and loess soils, there is no indication to expect a different relation between both indicators for arable and horticultural farms.

This relation is expected to be different and less evident for farm types on clay where the cultivation of crops such as Brussels sprouts, cauliflower and headed cabbages is common. These crops have a high N-demand while the residual soil mineral-N at harvest remains low (see chapter 5).

Application of manure in spring affects this relationship considerably since it leads to an increasing total farm N-surplus while the soil residual mineral-N remains at the same level. This increase is caused by the ineffective part of the nitrogen in the manure.

The high soil mineral N-values at harvest predicted in horticultural farms, relatively to arable farms, are mainly caused by the low ability of horticultural crops to absorb nitrogen (see chapter 5).

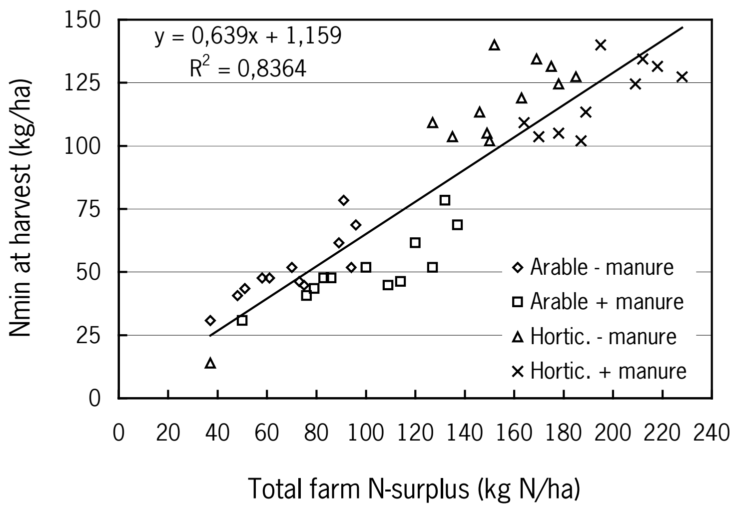


*Figure 9.4. Relation between total farm N-surplus and soil mineral-N at harvest(0-100 cm) for farms growing arable crops and field vegetables on sandy and loess soils.*

### 9.3.5 Relating soil mineral-N at harvest to 1 December

Figure 9.5 shows a clear linear relation between soil mineral-N at harvest and December first. The highest values were predicted in the horticultural farms (except the farm cultivating fine carrots only). The various processes that affect the amount of soil mineral-N between harvest and December first, compensate each other to a similar extent. This accounts for the considered farm types only and is expected to be less evident for other conditions. Spring application of manure had an insignificant effect on this relation. Loess soils deviate slightly from this relation because the loss through N-leaching in the period of harvest to December first is expected to be less for loess than for sandy soils.

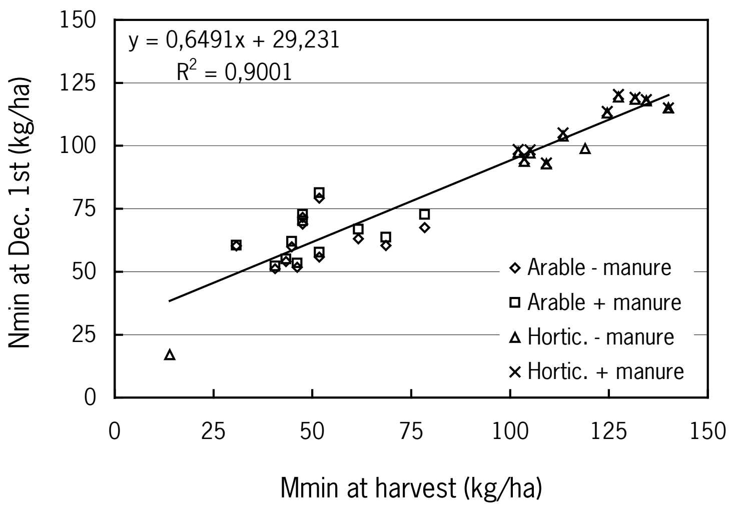


*Figure 9.5. Relation between soil mineral-N (0-100 cm) at harvest and 1st of December for farms growing arable crops and field vegetables on sandy and loess soils.*

### 9.3.6 Relating Minas-surplus with soil mineral-N at 1 December

This relation (Figure 9.6) is weak because both indicators are indirectly related. The various factors that may affect this relationship have been discussed in 9.3.1 to 9.3.5.

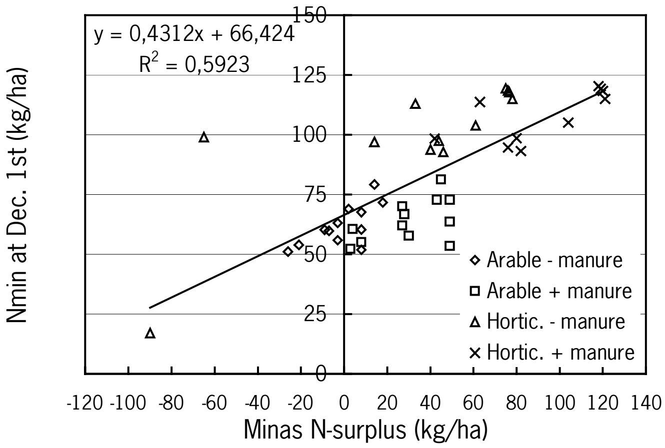


*Figure 9.6. Relation between Minas N-surplus and soil mineral-N at 1st December(0-100 cm) for farms growing arable crops and field vegetables on sandy and loess soils.*

## 9.4 Major conclusions

- For the 24 farms considered, Minas surplus showed a good and linear relation with the total farm N-surplus. However, Minas surplus is on average about 90 kg N/ha less than the total farm N-surplus. Major factors contributing to this difference are the fixed output according to the Minas regulation and the N-deposition. Application of manure does not affect this relation because it changes both indicators equally.
- The total N-surplus at the parcel (crop) level provides little information on the Minas and total farm N-surplus as long as knowledge regarding the crop rotation is lacking. This is caused by the differences in N-demand and N-output among the various crops.
- The total N-surplus is better related to soil mineral-N at harvest than the Minas N-surplus. This is mainly due to the differences in N-output among the crops. The major factor of variation in the relation between the total N-surplus and soil mineral-N at harvest is caused by the application of animal manure. This is due to the non-effective part of the nitrogen in manure.
- A clear relation was found between the residual soil mineral-N at harvest and December first. The various processes of loss and supply compensated each other to a similar extent. For different conditions and crop rotations this relation is expected to be less evident.
- Minas-surplus and soil mineral-N at harvest and December first are poorly related since both indicators are only indirectly linked.
- There was no reason to differentiate arable from horticultural farms on sandy and loess soils. Both types of farms show similar relations between the indicators discussed. However, the values of all indicators are higher for horticultural than for arable farms. All relations between the indicators are approximately linear.
- The relations between the indicators at the farm level, as studied in this chapter, are based on averages (see chapters 5 and 6) at the crop and parcel levels. However, the large variation observed at the crop and parcel levels is consequential for the relations at the farm level. A more comprehensive risk analysis will be necessary for a proper evaluation of the monitored indicators.

# 10. Relations between farm N-surplus and other indicators for nitrate loss: dairy systems

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## 10.1 Introduction

This chapter's aim is to present the relationships between the nitrogen surplus on paddock level and the nitrogen surplus on farm level, for dairy farming on sandy soils in the Netherlands. The relationship between the nitrogen surplus and the accumulation of mineral nitrogen ($N_{min,H}$) on paddock level is also investigated. All results refer to model calculations.

## 10.2 Types of dairy farms

Eighty different dairy farm configurations were defined as the basis of a simulation study (Appendix V). For this purpose the model BBPR (farm budgeting program for dairy cattle; Van Alem & Van Scheppingen, 1993) was used. To quantify the accumulation of mineral nitrogen ($N_{min,H}$) in the sandy soil during the fall, the model NURP (Vellinga *et al.*, 1997) has been used.
General characteristics for all farm situations: a milk quotum of 500,000 kg; a milk yield of 8,000 kg per cow per year; the replacement rate of the cattle is 30 % per year, whereas feeding and applying fertiliser was supposed to be accurate and according to current advisory systems. The farm configurations varied with respect to six different characteristics, which were supposed to affect the nitrogen surplus at paddock and farm level.

- **Stocking rate**, quota per ha
  Calculations were made using two different quotas per ha: 10,000 and 15,000 kg milk. This was not only associated with different stocking rates under grazing circumstances, but also with different amounts of slurry that is available for nitrogen application on the different paddocks.
- **Nitrogen application**
  Calculations were made using two different levels of nitrogen application on grassland: 250 and 350 kg N per ha per year. These doses represent the sum of fertiliser-N and effective nitrogen in slurry.
- **Soil type - Groundwater**
  Two different soil types were chosen. One is a sandy soil with groundwater class Gt VII, which is very sensitive to drought and nitrate leaching. The other is a sandy soil with groundwater class Gt IV, which is less sensitive to drought and nitrate leaching. The sandy soil GtIV was associated with higher crop (grass and maize) yields.
- **Grazing system**
  The grazing system and the number of grazing hours are expected to affect the nitrogen surplus. In areas with sandy soils farmers mainly use a restricted grazing system, which means that cows graze only during daytime. In this study calculations have been made using three different grazing systems: B4+4.5 (grazing during daytime, feeding 4.5 kg dm maize during the night and changing paddocks after 4 days; heifers and calves graze day and night), B4+8 (grazing during daytime, feeding 8 kg dm maize during the night and changing paddocks after 4 days; heifers and calves graze day and night) and summerfeeding (no grazing at all and all animals are kept indoors all year long; they feed on conserved roughage).

- **Percentage of maize in crop plan**
  On sandy soils, dairy farms generally grow a considerable amount of maize. Especially on soils that are very sensitive to drought: maize is less sensitive to drought than grass. Maize also requires lower nitrogen doses than grass to achieve the same dry matter yield. In this study, nitrogen was applied on maize at 150 kg per ha in all eighty farm configurations. Maize occupied either 15 % or 25 % of the total farm acreage.
- **Grassland used only for cutting**
  Grazing is expected to influence the nitrogen surplus and the nitrate leaching considerably. In half of the farm configurations with grazing, therefore, 10 % of all grassland is reserved for cutting all year round.

Appendix V shows an overview of all 80 calculated farm configurations.

## 10.3 Indicators in calculations

Several nitrogen surplus indicators were calculated: the nitrogen surplus on farm level; the MINAS-nitrogen surplus on farm level; the nitrogen surplus for grazed grassland (alternated with cutting); the nitrogen surplus for grassland only intended for cutting; the nitrogen surplus for maize land. These surpluses were calculated as follows.

- **Nitrogen surplus on farm level**
  In this definition concentrate, roughage, fertiliser, litter, and ammonium deposition are viewed as inputs. Cattle, milk and roughage are outputs. No manures are im- or exported. No cattle is imported. Further, nitrogen fixation is ignored in these calculations.
- **MINAS-nitrogen surplus on farm level**
  In this definition concentrate, roughage and fertiliser rank as input. Litter and deposition do not belong to the MINAS-nitrogen surplus. No manures are im- or exported. No cattle is imported. Cattle, milk, roughage and 'animal correction' are outputs. The so-called 'animal correction' entry refers to inevitable gaseous losses.
- **Nitrogen surplus for grazed grassland (alternated with cutting)**
  In this definition, faeces and urine from grazing animals, slurry, fertiliser and deposition are viewed as inputs. Grass intake by animals and removal of cut grass are outputs.
- **Nitrogen surplus for grassland only intended for cutting**
  In this definition, slurry, fertiliser and deposition are counted as inputs. Removal of cut grass is output.
- **Nitrogen surplus for maize land**
  In this definition, slurry, fertiliser and deposition are counted as inputs. Removal of cut maize is output.
- **Mineral nitrogen**
  This is the amount of mineral nitrogen, that is present in the paddock's soil (until 100 cm below the surface) in the autumn.

## 10.4 Surpluses on farm and paddock level

To show roughly the relationship between the nitrogen surplus at farm level ('true' and MINAS surplus) and the nitrogen surplus on paddock level, the results have been plotted in several graphs. Figure 10.1 shows the relationship between the nitrogen surpluses for paddocks with differences in use and the nitrogen surplus on farm level. Figure 10.2 shows the relationship between the nitrogen surpluses for paddocks with differences in use and the MINAS-nitrogen surplus on farm level. Apart from the level of the nitrogen surplus on the horizontal axis, both figures show great similarities. The MINAS-N-surplus level is lower than the real N-surplus level. This is caused by the facts that deposition and litter do not belong to the MINAS-surplus, whereas the 'animal correction' for gaseous losses ranks as an extra N-output.

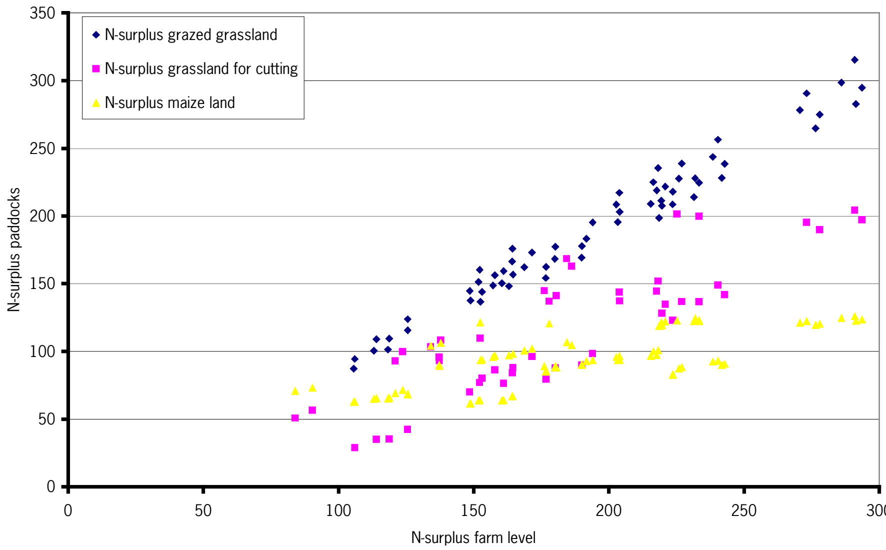


*Figure 10.1. Relationship between Nitrogen surpluses for paddocks with differences in use (kg/ha) and nitrogen surplus on farm level (kg/ha).*

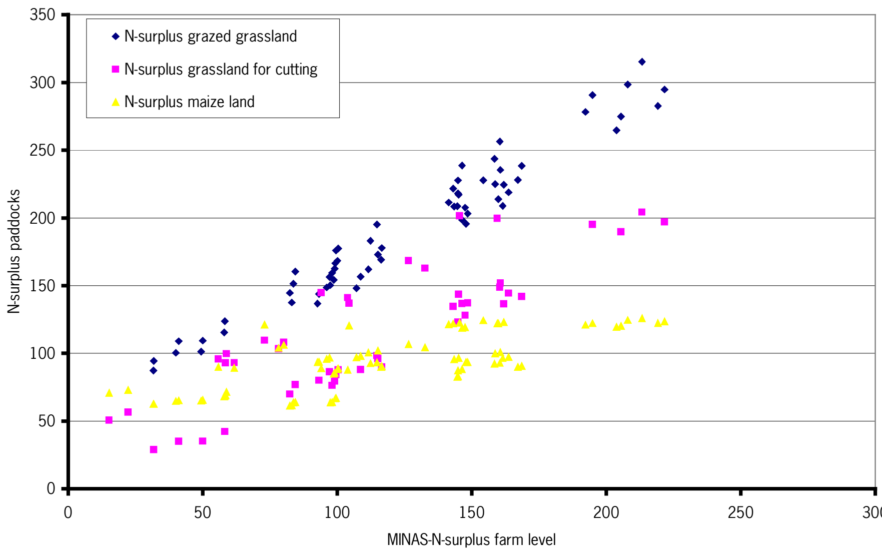


*Figure 10.2. Relationship between Nitrogen surpluses for paddocks with differences in use (kg/ha) and MINAS-nitrogen surplus on farm level (kg/ha).*

Because of the similarities between the 'true' farm N-surplus and the MINAS-N-surplus, the MINAS-N-surplus is not used in the remainder of this chapter to illustrate the relationship between the farm N-surplus and paddock N-surplus.
Table 10.1 shows the range in paddock N-surplus for different ranges of N-surpluses at farm level. From this, but also from Figure 10.1 and Figure 10.2, the average N-surplus for grazed paddocks appears to be higher than for cut grass and maize paddocks. It is also clear that the higher the farm N-surpluses are, the larger the difference for paddock surpluses. Further the low variation in N-surplus for maize land attracts attention. The main reason for this is that in this study the nitrogen application level has been 150 kg effective N for all cases.

*Table 10.1. Range in N-surpluses for different paddocks (grazing, cutting, maize, all) related to different categories for N-surplus on farm level.*

| Nitrogen surplus (kg N/ha farm level) | N-surplus for grazed grassland (kg/ha) | N-surplus for cutting grassland (kg/ha) | N-surplus for maize land (kg/ha) | Range N-surplus for all paddocks (kg/ha) |
|---|---|---|---|---|
| <125 kg/ha | 85 – 125 | 30 – 100 | 60 – 70 | 30 – 125 |
| 125 – 175 kg/ha | 135 – 175 | 70 – 110 | 60 – 120 | 60 – 175 |
| 175 – 225 kg/ha | 155 – 235 | 80 – 200 | 80 – 120 | 80 – 235 |
| 225 – 275 kg/ha | 210 – 290 | 120 – 200 | 80 – 120 | 80 – 290 |
| > 275 kg/ha | 265 – 315 | 190 – 205 | 120 – 125 | 120 – 315 |

## 10.5 Separate factor influence

In this study calculations have been made using variation in soil type, stocking rate, nitrogen application for grassland, percentage of maize in crop plan, the fraction of grassland area used only for cutting, and the grazing system. This paragraph shortly describes how these factors affect the different paddock N-surpluses.

### 10.5.1 Groundwater

Figure 10.3 and Figure 10.4 show the relationship between paddock N-surplus and the farm N-surplus for two levels of drought sensitivity as implied by the groundwater table, respectively GT-IV and GT-VII. It is remarkable that the levels of both paddock N-surplus and farm N-surplus differ strongly between ground water tables, whereas the relation between the two variables (see also Figure 10.1), does not change. Using the same starting points, the sandy soil Gt IV, which is hardly sensitive to drought (Figure 10.3) results in lower paddock and farm N-surplus than the sandy soil Gt VII, which is very sensitive to drought (Figure 10.4). Figure 10.1 combines all data in Figures 10.3 and 10.4.

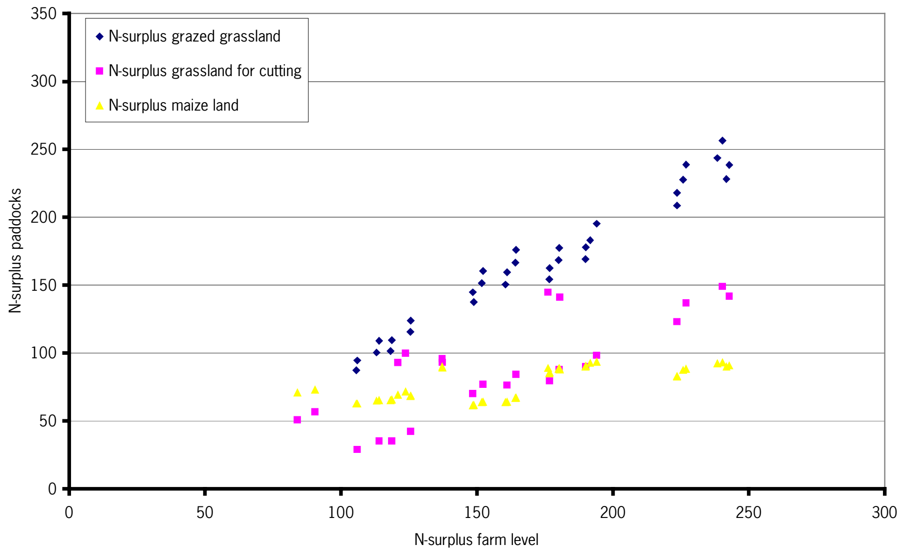


*Figure 10.3. Relationship between N-surpluses for paddocks with differences in use (kg/ha) and nitrogen surplus at farm level (kg/ha) for a sandy soil with GtIV (good water availability).*

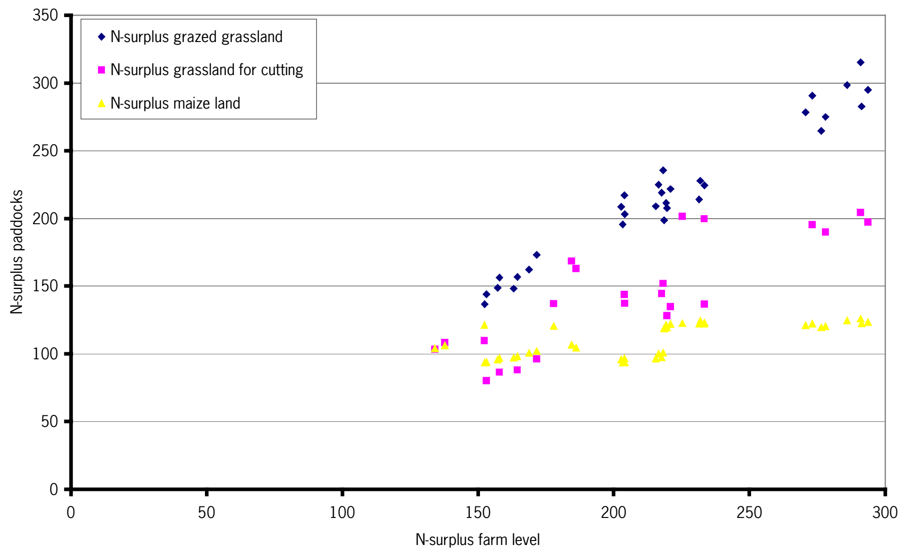


*Figure 10.4. Relationship between N-surpluses for paddocks with differences in use (kg/ha) and nitrogen surplus at farm level (kg/ha) for a sandy soil with GtVII (drought sensitive).*

### 10.5.2 Stocking rate

Based on the simulations, it appears that higher stocking rates result in a higher farm nitrogen surplus levels. Paddock surpluses from high farm surpluses (> 225 kg per ha) only concern situations that have high stocking rates. These paddock surpluses are higher than resulting from low stocking rates, but the farm nitrogen surplus is higher as well.
Several farm N-surpluses come from both high and low stocking rates. This especially concerns farm configurations that do not graze any cattle. Apart from this, high stocking rates result in higher nitrogen surpluses for grassland for cutting and maize land than low stocking rates.

### 10.5.3 Nitrogen application

Generally high N-application levels result in high N-surpluses at farm level. In the calculations for this study we used two nitrogen application levels: 250 kg N per ha (low level) en 350 kg per ha (high level). Situations with the low level did not result in N-surpluses on farm level any higher than 250 kg per ha. Sandy soils with Gt IV have no low N-application level above 200 kg N per ha nitrogen surplus. Below 150 kg N per ha farm nitrogen surplus only situations occur with a low N-application level. This limit is 175 kg N per ha farm nitrogen surplus for sandy soils, which is very sensitive to drought. In the range that both low and high N-application result in same N-surpluses, high N-applications always lead to a higher N-surplus for grassland.
The variation for maize land is considerably smaller, especially due to applying N on maize land on the same level in each situation.

### 10.5.4 Grazing system

In this study when animals graze, calculations have been made using two different grazing systems: B4+4.5 and B4+8 (heifers and calves graze day and night). So cows graze only during daytimes and get either 4.5 kg dm maize of 8 kg ds maize per day. The more maize was fed, the lower the N-surpluses. Situations have also been calculated using 'summerfeeding' as system. This means that animals stay indoors all year long. Summerfeeding results in the lowest farm N-surpluses. Further summerfeeding with grassland only for cutting, results in a lower paddock surplus for grassland than farm situations with grazing do for grazed paddocks. However, grassland only used for cutting in summerfeeding situations have higher N-surpluses than grassland only used for cutting in farm situations including grazed grassland. This is caused by the amount of slurry applied on those very paddocks. Grazing causes a lot of organic N on the paddocks. A certain amount of this organic N can not be used for growth. Summerfeeding situations mean that all animal faeces and urine will be stored and effective applied. The slurry will be applied on grassland and maize. The slurry applied on grassland in summerfeeding situations is higher than on grassland only used for cutting in situations that graze animals. For less slurry is available for grassland only used for cutting in situations that graze animals. This means that more N with fertiliser is applied, which can be used more efficiently than slurry.

### 10.5.5 Percentage of maize in cropping pattern

Variation in percentage of maize in the crop plan mainly affects paddock N-surpluses for grassland. Starting from the same level for N-surplus on farm level, a high percentage of maize in the crop plan results in slightly increasing N-surplus for grassland especially grazed paddocks. The explanation is as follows. A high percentage of maize in the crop plan leads to a more intense use of grassland. Losses (especially faeces and urine) per ha grassland will increase.

### 10.5.6 Fraction of grassland used only for cutting

In farm situations that graze animals, the percentage of grassland used only for cutting has been varied: 0 and 10 %, respectively, of all grassland area was used only for cutting in the calculations. The effect for grazed paddocks is equal to the effect described for '*Percentage of maize in cropping pattern'*. The fact is that a high percentage of grassland used only for cutting results in a higher N-surplus for grazed paddocks than doesa low percentage of grassland used only for cutting. The reason, more intense use of grazed paddocks, is also equal as described for '*Percentage of maize in cropping pattern'*. The N-surplus for maize land does not change by this factor.

## 10.6 Farm nitrogen surplus and mineral N in soil

Paddock surpluses have been calculated using BBPR (Van Alem & Van Scheppingen, 1993). But for all simulated farm situations (Appendix V) also the amount of mineral N on farm level has been estimated. The simulation program NURP was used for this purpose (Vellinga *et al.*, 1997). Especially for maize land, NURP gives only a coarse approximation of soil mineral N in autumn, and this aspect should be improved. For example NURP does not account for differences in sensitivity for drought.
Figure 10.5 shows the relationship between the mineral soil N in autumn (0 – 100 cm) and the nitrogen surplus at farm level. A positive correlation between these variables is found, though the variation is wide. Figure 10.6 shows the relationship between the amount of mineral N in the fall for paddocks with differences in use and the N-surplus on farm level. Figure 10.7 shows the relationship between the amount of mineral N in the fall for paddocks with differences in use and the MINAS-N-surplus at farm level. Besides the N-surplus level on the horizontal axis, both figures show great similarities. The MINAS-N-surplus level is lower than the 'real' farm surplus level, because deposition and litter do not belong to the MINAS-surplus, whereas the animal correction ranks as an extra formal output from the farm.

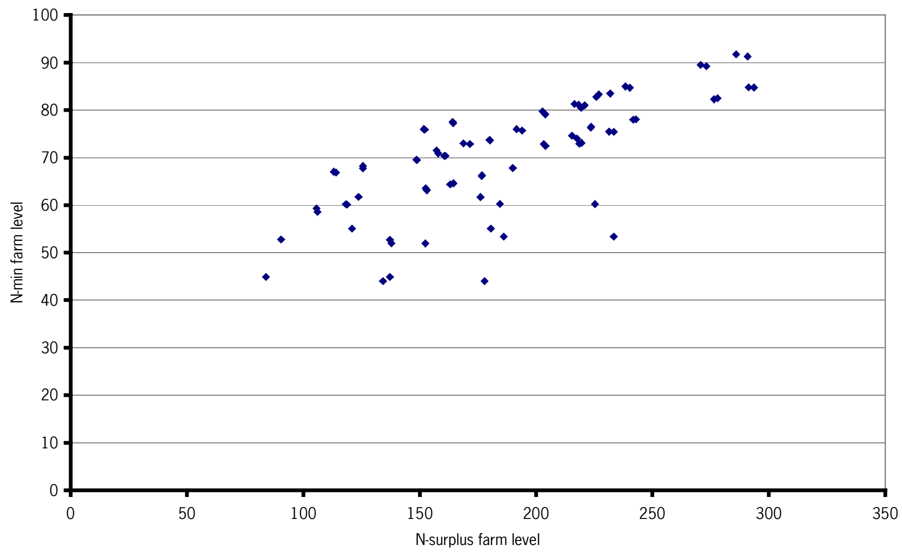


*Figure 10.5. Relationship between fall's mineral N (0 – 100 cm) (kg/ha) and nitrogen surplus at farm level (kg/ha).*

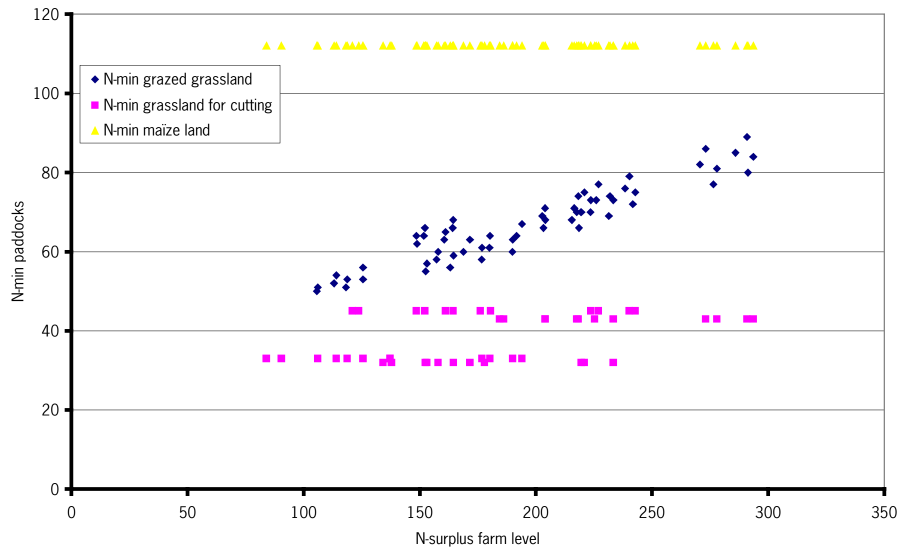


*Figure 10.6. Relationship between fall mineral N (0 – 100 cm) for paddocks with differences in use (kg/ha) and nitrogen surplus at farm level (kg/ha).*

Based on the presumptions listed earlier, Figure 10.6 and Figure 10.7 show that the highest amounts of mineral N are expected under maize; a constant level of more than 110 kg mineral N is found here per ha.

The amount of mineral N under grazed grassland increases as the farm N-surplus increases. Soil type, nitrogen application, grazing system and stocking rate have a considerable effect. A soil type which is very sensitive to drought shows more mineral N in the fall than a soil type with good water storing ability. High N application results in more mineral N under grassland than low N application. Low grazing pressure results in less mineral N under grassland than high grazing pressure. Further, high stocking rates result in more mineral N under grassland than low stocking rates.

Grassland used for cutting only results in the lowest mineral N. This goes for grassland belonging to farm types with summerfeeding, where neither cows nor young stock graze. A relationship between N-surplus and the fraction of grassland only used for cutting to influence the mineral N level has not been found in these calculations. The differences in mineral N, Figure 10.6 and Figure 10.7, are caused by the differences in N-application. High N application levels result in more mineral N under grassland in the fall than low application levels. Soil type also has some (small) influence on the mineral N under grassland.

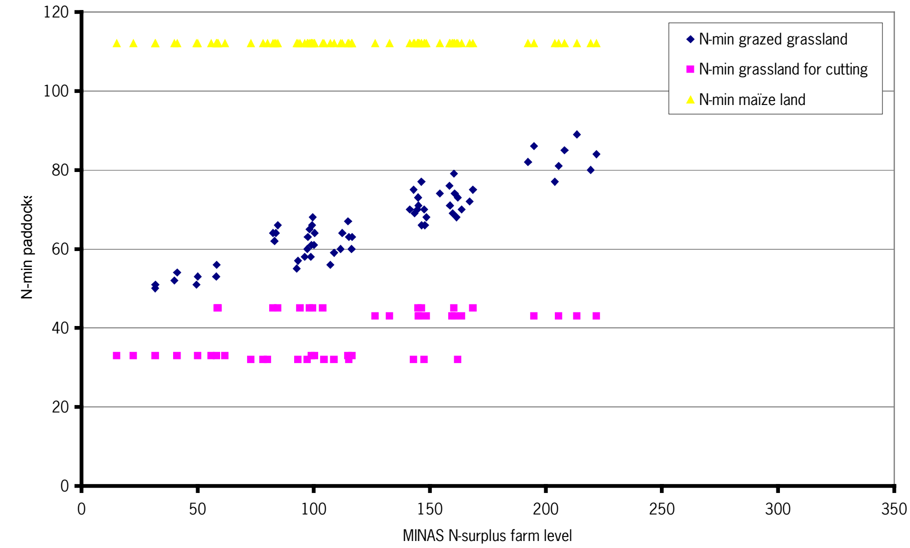


*Figure 10.7. Relationship between fall mineral N (0 – 100 cm) for paddocks with differences in use (kg/ha) and MINAS-nitrogen surplus on farm level (kg/ha).*

Purely for illustration Figure 10.8 shows the relationship between the N-surplus for paddocks with differences in use and the mineral N under paddocks with differences in use. The effects are fully comparable to the described relationship between the N-surplus *on farm level* and the amount of mineral N under different paddocks.

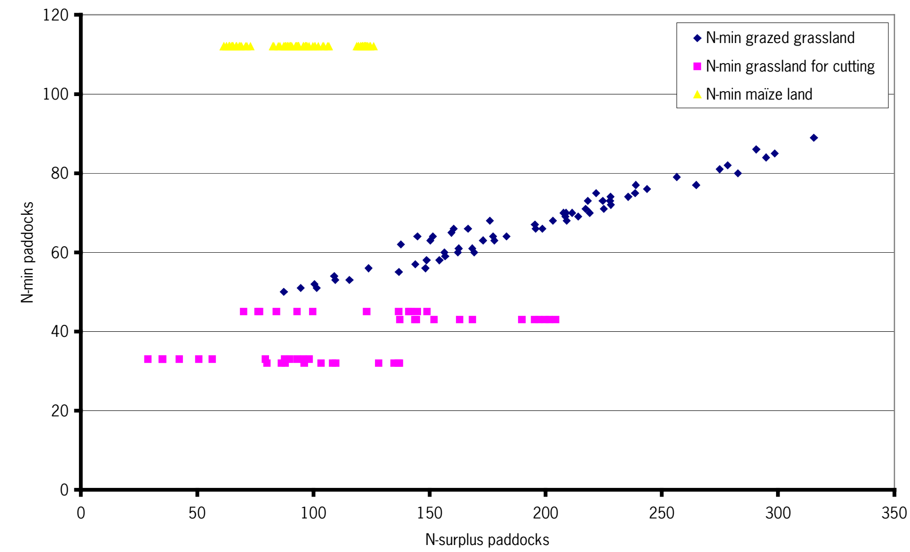


*Figure 10.8. Relationship between fall mineral N (0 – 100 cm) for paddocks with differences in use (kg/ha) and the nitrogen surplus for paddocks with differences in use (kg/ha).*

## 10.7 Conclusions

Calculations based on 80 different farm configurations show clear relationships between the N-surplus at farm level and the N-surpluses for paddocks with differences in use:

1. The N-surplus for grazed grassland increases as the farm N-surplus increases.
2. The N-surplus on grassland that is only used for cutting increases as the farm N-surplus increases, but less so than the increase observed on grazed grassland.
3. Considering the used starting points, the N-surplus for maize land shows little variation and increases slightly as the farm N-surplus increases.
4. The nitrogen surplus for grazed paddocks is high under: high nitrogen application, high fraction of grassland area used for cutting only, and high percentage maize in crop plan. A drought sensitive soil type also results in high N-surpluses for grazed paddocks.
5. The nitrogen surplus for grassland used for cutting only is high under the following conditions: summerfeeding the cattle, high N-application level, and high stocking rate. A drought-sensitive soil type also results in high N-surpluses for paddocks only used for cutting.
6. The nitrogen surplus for maize paddocks is low due to soil having good water storing ability rather than to drought sensitive soil types. Besides the influence of soil type, in these calculations the paddock's N-surplus for maize hardly changes.
7. Considering the used starting points, NURP calculations show no relation between the mineral N under maize land and the farm's nitrogen surplus.
8. These calculations hardly show any relationship between the mineral N under paddocks only used for cutting and the farm N-surplus. Though soil type and nitrogen application level affect the amount of soil mineral N in autumn.
9. The soil mineral N in autumn under grazed paddocks increases as the farm N-surplus increases. The values are affected by soil type, N-application level, grazing system and stocking rate.

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# Appendix I.
## Overview of the results per combination of crop – soil type – growing period

This is an appendix to Chapter 5.

| No | Crop | Soil type | Cult.[1] period | No observations | Recomm. N-rate | Model[2] | $N_{min,H}$ at $N_{recommended}$ | $N_{min,H}$ max-90%[3] | $N_{min,H}$ at N-rate = 0 α | Model parameters β | γ | Remarks[4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ware potatoes | clay | - | 166 | 245 | non-linear | 71 | 110 | 42 | 123 | 409 | |
| 2 | ware potatoes | sand | - | 45 | 255 | none | 63 | 92 | - | - | - | small range N-rate |
| 3 | ware potatoes | loess | - | 64 | 245 | linear | 67 | 105 | 26 | 0.168 | - | 0-90->60cm |
| 4 | ware potatoes | all types | - | 275 | 245 | non-linear | 67 | 105 | 42 | 214 | 554 | total of no. 1-3 |
| | | | | | 255 | | 70 | 107 | | | | |
| 5 | starch potatoes | sand | - | 165 | 230 | none | 44 | 80 | - | - | - | 104s,52rps; |
| 6 | seed potatoes | clay | - | 21 | 120 | none | 56 | 81 | - | - | - | |
| 7 | sugar beet | clay | - | 165 | 140 | none | 15 | 27 | - | - | - | no clear relation |
| 8 | sugar beet | sand | - | 78 | 140 | linear | 26 | 63 | 21 | 0.036 | - | 32rps,46s |
| 9 | sugar beet | loess | - | 79 | 140 | linear | 24 | 50 | 5 | 0.143 | - | 0-90->60cm |
| 10 | sugar beet | sand, loess | - | 157 | 140 | linear | 25 | 57 | 10 | 0.106 | - | |
| 11 | silage maize | clay | - | 83 | 155 | linear | 43 | 98 | 6 | 0.239 | - | |
| 12 | silage maize | sand | - | 773 | 155 | non-linear | 78 | 142 | 35 | 94 | 179 | |
| 13 | grain maize | sand | - | 60 | 155 | linear | 48 | 69 | 18 | 0.192 | - | |
| 14 | silage maize | loess | - | 64 | 155 | linear | 38 | 65 | 8 | 0.191 | - | 0-90->60cm |
| 15 | silage maize | clay, loess | - | 147 | 155 | linear | 41 | 77 | 7 | 0.221 | - | |
| 16 | silage/grain maize | sand | - | 833 | 155 | non-linear | 76 | 139 | 34 | 101 | 190 | |
| 17 | winter wheat | clay | - | 78 | 220 | linear | 22 | 43 | 11 | 0.049 | - | partly 0-90->60cm |
| 18 | winter wheat | sand | - | 18 | 180 | none | 38 | 56 | - | - | - | 1rps,17s; small range N-rate |
| 19 | winter wheat | loess | - | 24 | 220 | none | 20 | 37 | - | - | - | 0-90->60cm |
| 20 | winter wheat | clay, loess | - | 102 | 220 | linear | 22 | 42 | 12 | 0.045 | - | |
| 21 | winter rye | sand | - | 11 | 120 | none | 31 | 50 | - | - | - | no clear relation |
| 22 | triticale | sand | - | 11 | 180 | none | 37 | 51 | - | - | - | small range N-rate |
| 23 | winter cereals | sand | - | 40 | 120-180 | none | 36 | 53 | - | - | - | N-rate depends on type of crop |
| 24 | spring cereals | clay | - | 9 | 140 | none | 19 | 26 | - | - | - | partly 0-90->60cm; no clear rel. |
| 25 | spring barley | clay | - | 42 | 60 | none | 16 | 23 | - | - | - | no clear relation |
| 26 | spring barley | sand | - | 8 | 60 | none | 23 | 48 | - | - | - | 2rps,6s;no clear relation |
| 27 | spring barley | all types | - | 50 | 60 | none | 17 | 29 | - | - | - | no clear relation |

| No | Crop | Soil type | Cult.[1] period | No observations | Recomm. N-rate | Model[2] | $N_{min,H}$ at $N_{recommended}$ | $N_{min,H}$ max-90%[3] | $N_{min,H}$ at N-rate = 0 α | Model parameters β | γ | Remarks[4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 28 | oats | all types | - | 9 | 110 | none | 16 | 22 | - | - | - | 7c,2s;no clear relation |
| 29 | spring cereals | all types | - | 68 | 60-140 | none | 17 | 28 | - | - | - | N-rate depends on growing period |
| 30 | seed onion | clay | - | 104 | 110 | linear | 60 | 96 | 33 | 0.245 | - | |
| 31 | cauliflower | clay | au | 24 | 155 | linear | 68 | 78 | 21 | 0.302 | - | |
| 32 | cauliflower | clay | su | 24 | 190 | none | 49 | 105 | - | - | - | no clear relation |
| 33 | cauliflower | clay | su,au | 48 | 155 | linear | 56 | 101 | 35 | 0.134 | - | |
| | | | | | 190 | | 61 | 106 | | | | |
| 34 | broccoli | all types | au | 20 | 190 | linear | 38 | 67 | 10 | 0.144 | - | 12c,8s |
| 35 | broccoli | sand | sp | 5 | 265 | none | 54 | 80 | - | - | - | insufficient observations |
| 36 | broccoli | clay | su | 36 | 230 | linear | 43 | 66 | 11 | 0.138 | | 36c,1s |
| 37 | broccoli | all types | all | 61 | 190 | linear | 39 | 60 | 13 | 0.137 | - | |
| | | | | | 230 | | 45 | 66 | | | | |
| | | | | | 265 | | 50 | 71 | | | | |
| 38 | Chinese cabbage | sand | au | 7 | 80 | none | 41 | 86 | - | - | - | insufficient observations |
| 39 | Chinese cabbage | sand | su | 5 | 110 | none | 61 | 117 | - | - | - | insufficient observations |
| 40 | Chinese cabbage | sand | all | 13 | 110 | none | 51 | 99 | - | - | - | 1sp,5su,7au |
| 41 | garden pea | sand | - | 28 | 20 | none | 25 | 36 | - | - | - | 28s,2c; no relation |
| 42 | perenial ryegrass | sand | - | 8 | 160 | none | 19 | 27 | - | - | - | small range N-rate |
| 43 | iceberg lettuce | all types | au | 20 | 75 | linear | 118 | 158 | 37 | 1.079 | - | 15s,5c |
| 44 | iceberg lettuce | sand | sp | 39 | 155 | non-linear | 98 | 186 | 29 | 468 | 318 | |
| 45 | iceberg lettuce | sand | su | 29 | 85 | linear | 106 | 244 | 11 | 1.117 | - | |
| 46 | iceberg lettuce | sand | su,au | 49 | 75 | linear | 101 | 214 | 20 | 1.077 | - | |
| | | | | | 85 | | 112 | 225 | | | | |
| 47 | root sellery | clay | - | 5 | 185 | none | 39 | 72 | - | - | - | insufficient observations |
| 48 | fennel | sand | sp | 1 | 125 | none | | | - | - | - | insufficient observations |
| 49 | head lettuce | sand | au | 2 | 105 | none | 80 | 109 | - | - | - | insufficient observations |
| 50 | head lettuce | all types | sp | 22 | 155 | none | 85 | 136 | - | - | - | 5c,17s |
| 51 | head lettuce | all types | su | 19 | 105 | none | 96 | 158 | - | - | - | 5c,13s,1rps |

| No | Crop | Soil type | Cult.[1] period | No observations | Recomm. N-rate | Model[2] | $N_{min,H}$ at $N_{recommended}$ | $N_{min,H}$ max-90%[3] | $N_{min,H}$ at N-rate = 0 α | Model parameters β | γ | Remarks[4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | head lettuce | all types | all | 43 | 105-155 | none | 89 | 133 | - | - | - | |
| 52 | leek | all types | au | 27 | 235 | linear | 91 | 152 | 7 | 0.357 | - | 1rps,5c,21s |
| 53 | leek | sand | wi | 26 | 235 | none | 24 | 41 | - | - | - | |
| 54 | leek | sand | su | 1 | 235 | none | | | - | - | - | insufficient observations |
| 55 | spinach | clay | au | 14 | 150 | none | 147 | 263 | - | - | - | 0-30->60cm |
| 56 | spinach | clay | sp | 15 | 255 | none | 107 | 254 | - | - | - | 0-30->60cm |
| 57 | spinach | clay | su | 6 | 180 | none | 98 | 164 | - | - | - | 0-30->60cm |
| 58 | spinach | clay | all | 35 | 180 | none | 122 | 246 | - | - | - | 0-30->60cm |
| 59 | dwarf French bean | sand | - | 26 | 125 | none | 45 | 92 | - | - | - | |
| 60 | field bean | sand | - | 7 | 0 | none | 54 | 88 | - | - | - | |
| 61 | carrot, fine | sand | au | 14 | 45 | none | 10 | 17 | - | - | - | |
| 62 | carrot, fine | sand | su | 1 | 45 | none | | | - | - | - | insufficient observations |
| 63 | winter oil-seed rape | sand | - | 3 | 125 | none | | | - | - | - | insufficient observations |
| 64 | carrot, winter | all types | - | 21 | 60 | none | 24 | 46 | - | - | - | 11c,1rps,9s |
| 65 | witloof chicory | clay/loess | - | 41 | 120 | linear | 24 | 46 | 7 | 0.142 | - | 31c,10ls; N-rate differs per variety |
| 66 | white cabbage | clay | au | 44 | 280 | non-linear | 27 | 41 | 17 | 248 | 916 | |
| 67 | Brussels sprouts | clay | - | 9 | 205 | none | 7 | 10 | - | - | - | |

1 *growing period: spring (sp), summer (su), autumn (au) and winter (wi)*
2 *non-lineair (eq. 5.1), lineair (eq. 5.2), none (no model used)*
3 *value of $N_{min\ H}$ that will be exceeded once every ten years when a farmer cultivates at the recommended N-rates.*
4 *number of observations for different soils: clay soils (c), sandy soils (s), retained peat soil (rps), (b) 90→60 cm observations originate from 0-90 cm soil layer.*

# Appendix II.

## Period of planting and harvest for field vegetables cultivated in different periods of the growing season

This is an appendix to Chapter 5.

| Crop | Name growing period period | Planting period | Harvest period |
|---|---|---|---|
| cauliflower | autumn | half june - start aug | end aug - start dec |
| cauliflower | summer | start may - end june | start july - start sept |
| broccoli | autumn | half june - start aug | end aug - half nov |
| broccoli | spring | start april - start may | start june- start july |
| broccoli | summer | start may - half june | start july - end aug |
| Chinese cabbage | autumn | end july - half aug | end sept - start nov |
| Chinese cabbage | summer | half april - end july | half june - end sept |
| iceberg lettuce | autumn | july – aug | sept - oct |
| iceberg lettuce | spring | end march – april | end may - june |
| iceberg lettuce | summer | may – june | july - aug |
| root cellery | summer | may – june | sept - oct |
| fennel | spring | end march - half april | half june - half aug |
| head lettuce | autumn | end july - start sept | sept - oct |
| head lettuce | spring | half march - half may | start may - end june |
| head lettuce | summer | half may - end july | july – aug |
| leek | autumn | start june - end june | start nov – end dec |
| leek | winter | start july - end july | start jan - may |
| leek | summer | start april - start may | end june – aug |
| spinach | autumn | start aug – end aug | end sept – end oct |
| spinach | spring | start march - start april. | half may – end may |
| spinach | summer | half april - start may | start june – end aug |
| carrot, fine | autumn | start april - end may | sept – nov |
| carrot, fine | summer | march | july – aug |
| carrot, winter | - | end april - start may | oct – nov |
| white cabbage | autumn | half april - may | sept - half nov |

# Appendix III.
# ANIMO Simulation results: correlations between nitrate and $N_{min}$

This is an appendix to Chapter 8.

## A. Cranendonck grassland

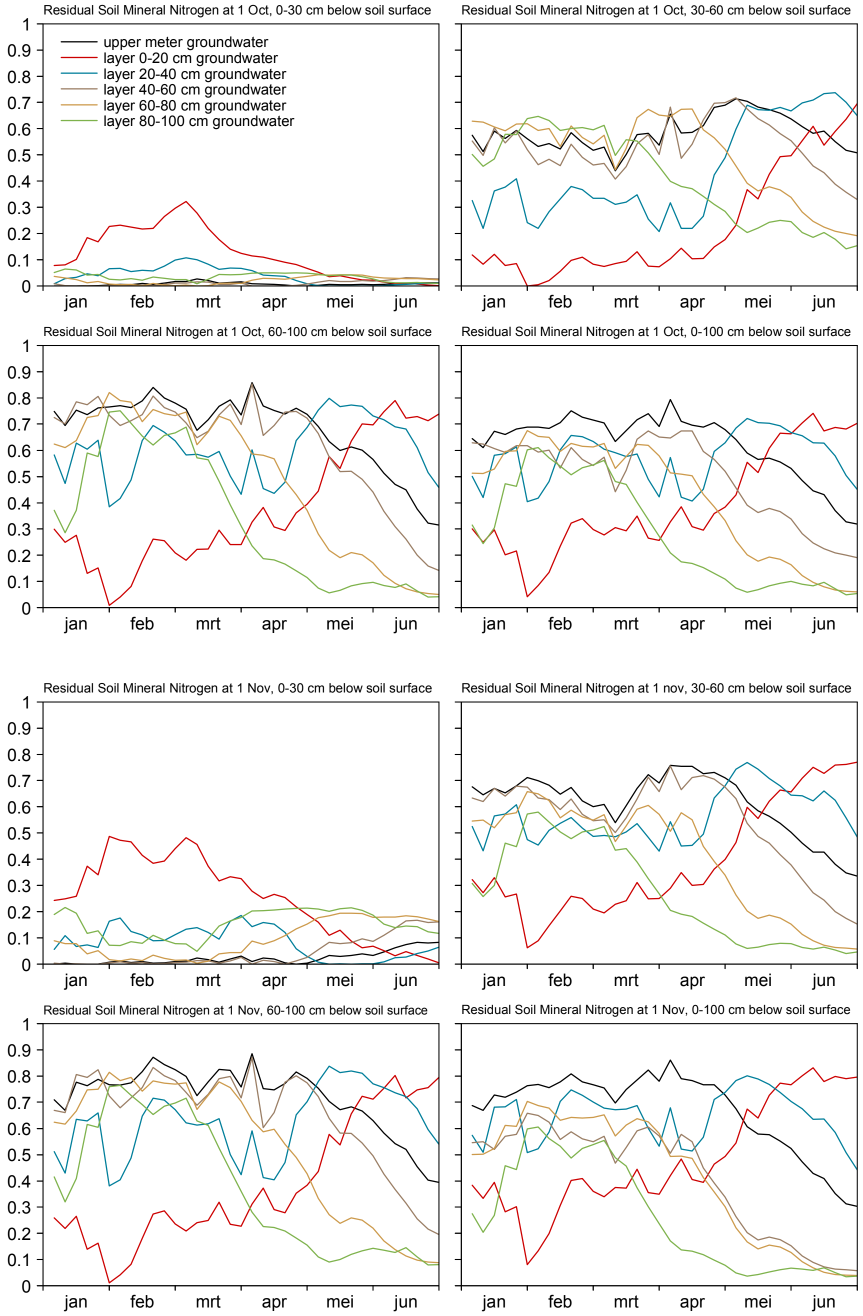


*Figure III.1. Correlation coefficient between different times and depths of nitrate sampling in the groundwater and different depths of residual soil mineral nitrogen at 1 October and 1 November (All simulated).*

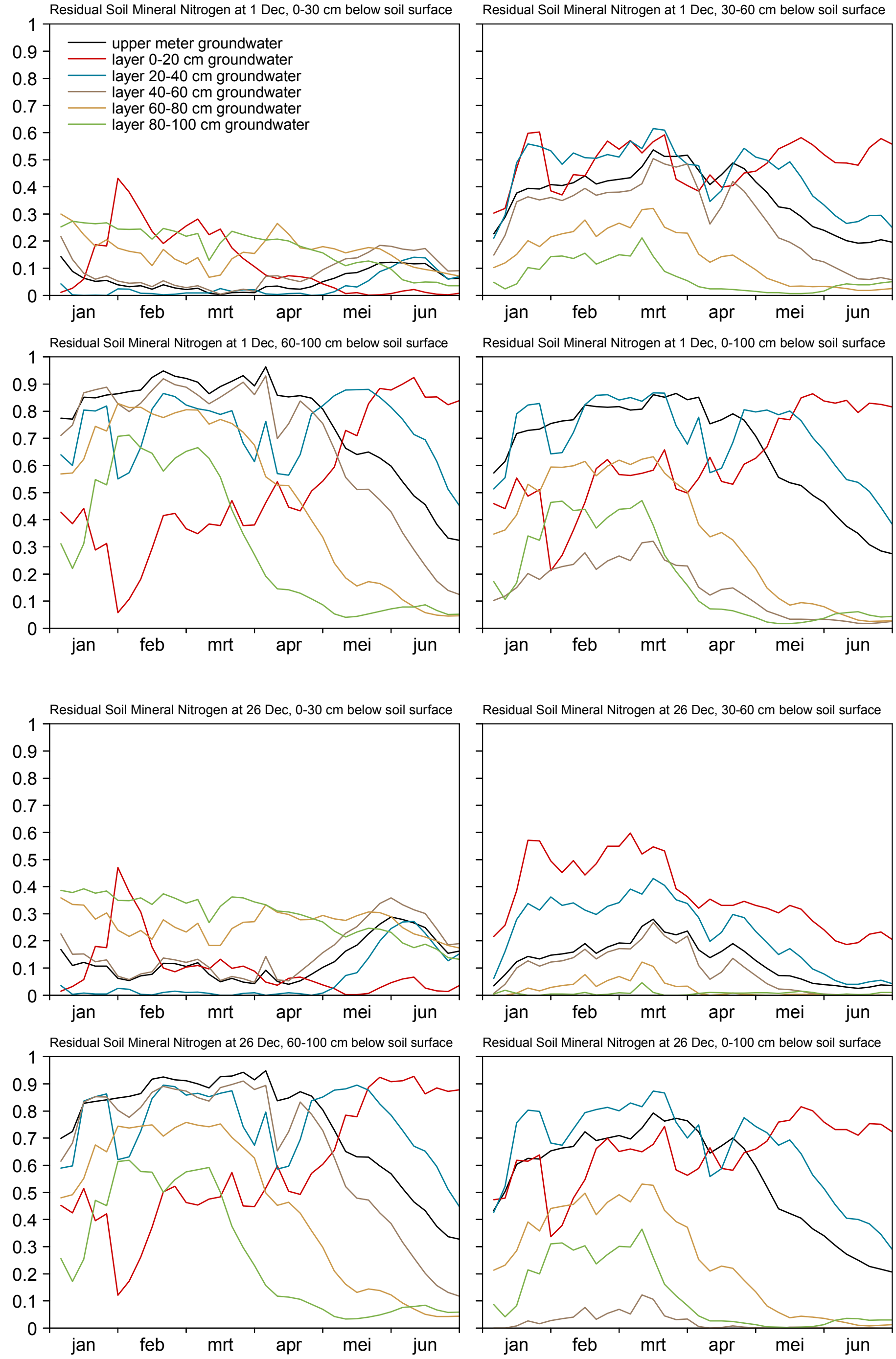


*Figure III.2 Correlation coefficient between different times and depths of nitrate sampling in the groundwater and different depths of residual soil mineral nitrogen at 1 December and 26 December (All simulated).*

## B. Ruurlo grassland

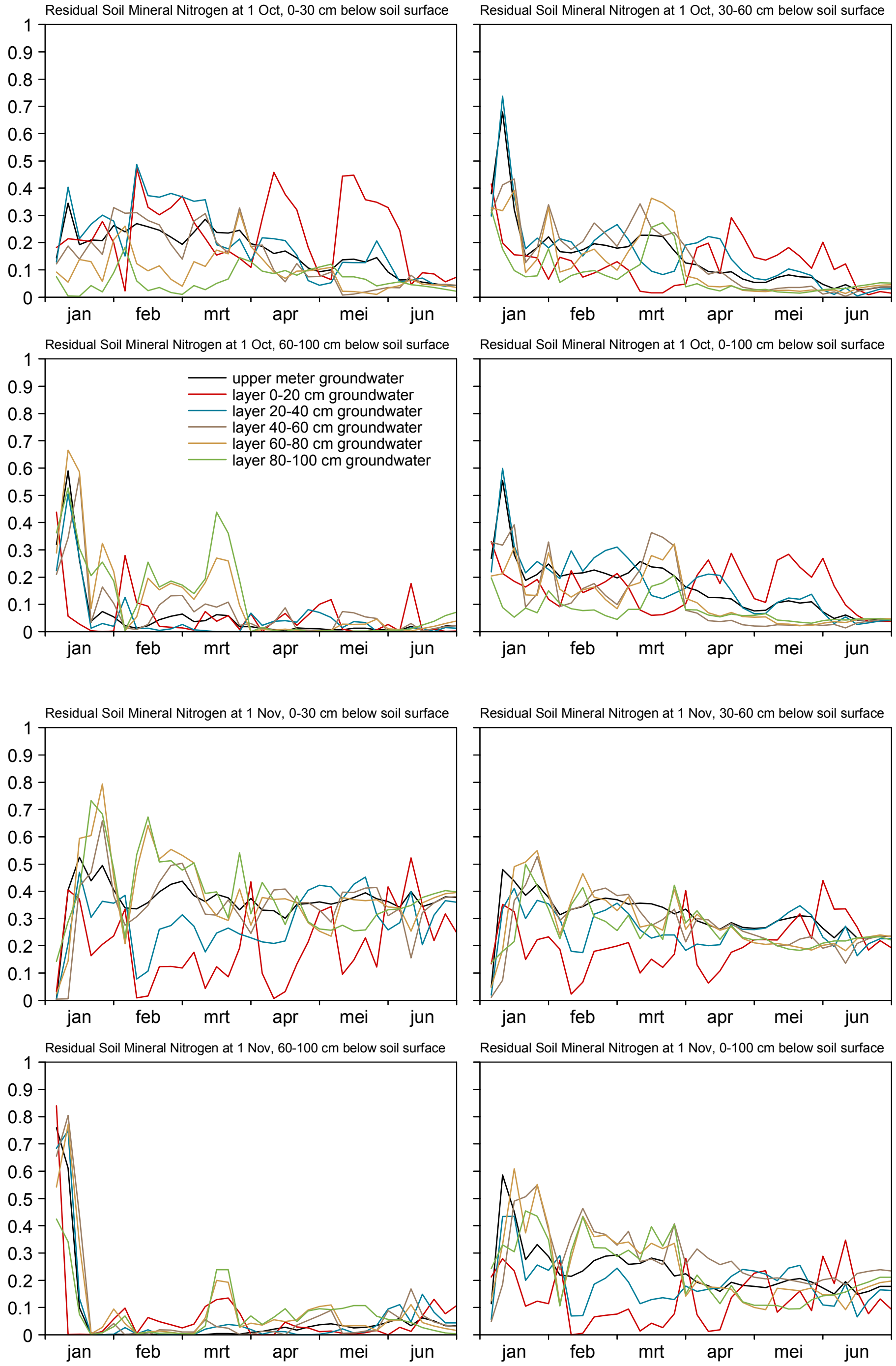


*Figure III.3. Correlation coefficient between different times and depths of nitrate sampling in the groundwater and different depths of residual soil mineral nitrogen at 1 October and 1 November (All simulated).*

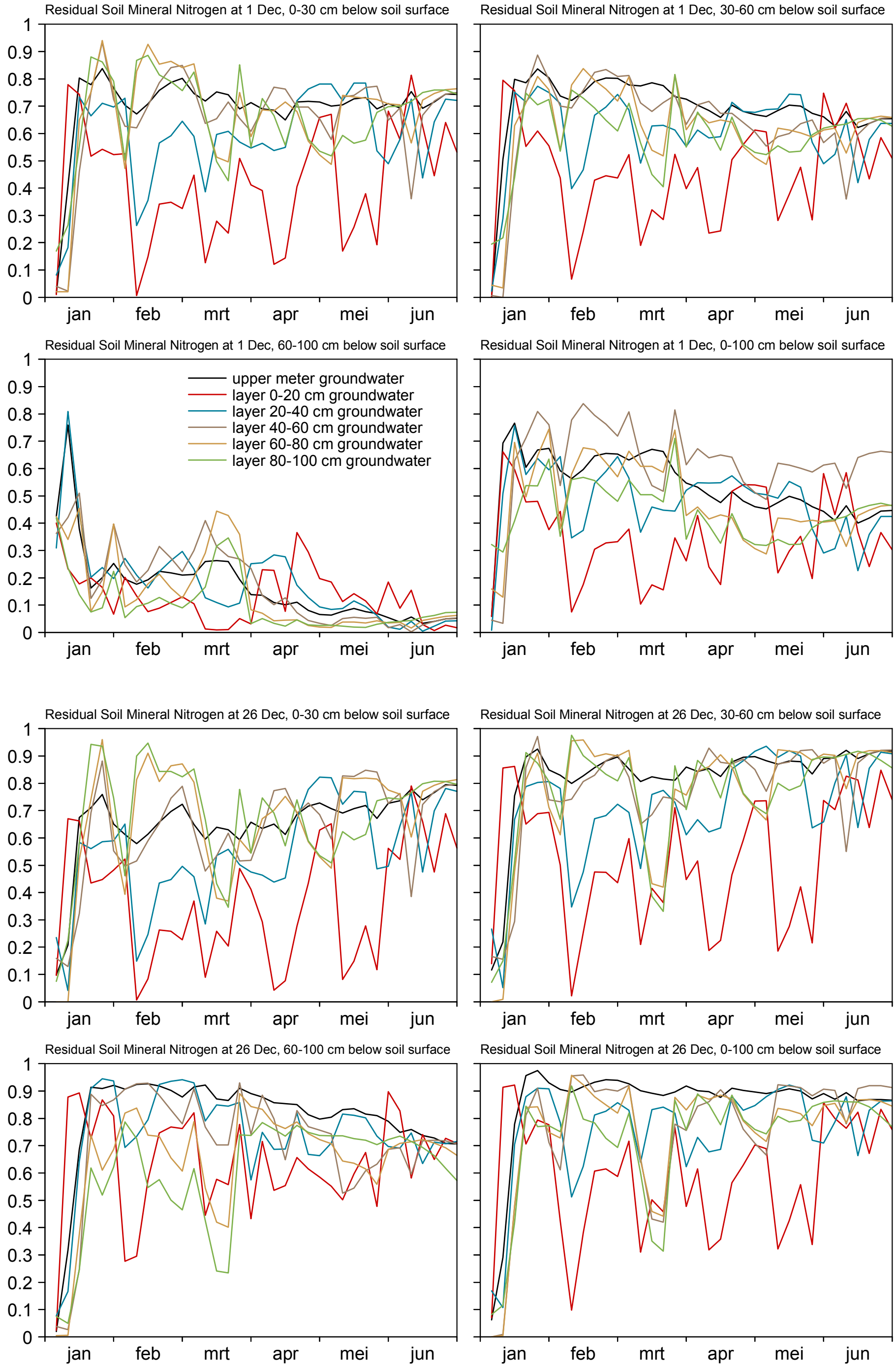


*Figure III.4. Correlation coefficient between different times and depths of nitrate sampling in the groundwater and different depths of residual soil mineral nitrogen at 1 December and 26 December (All simulated).*

## C. Cranendonck maize

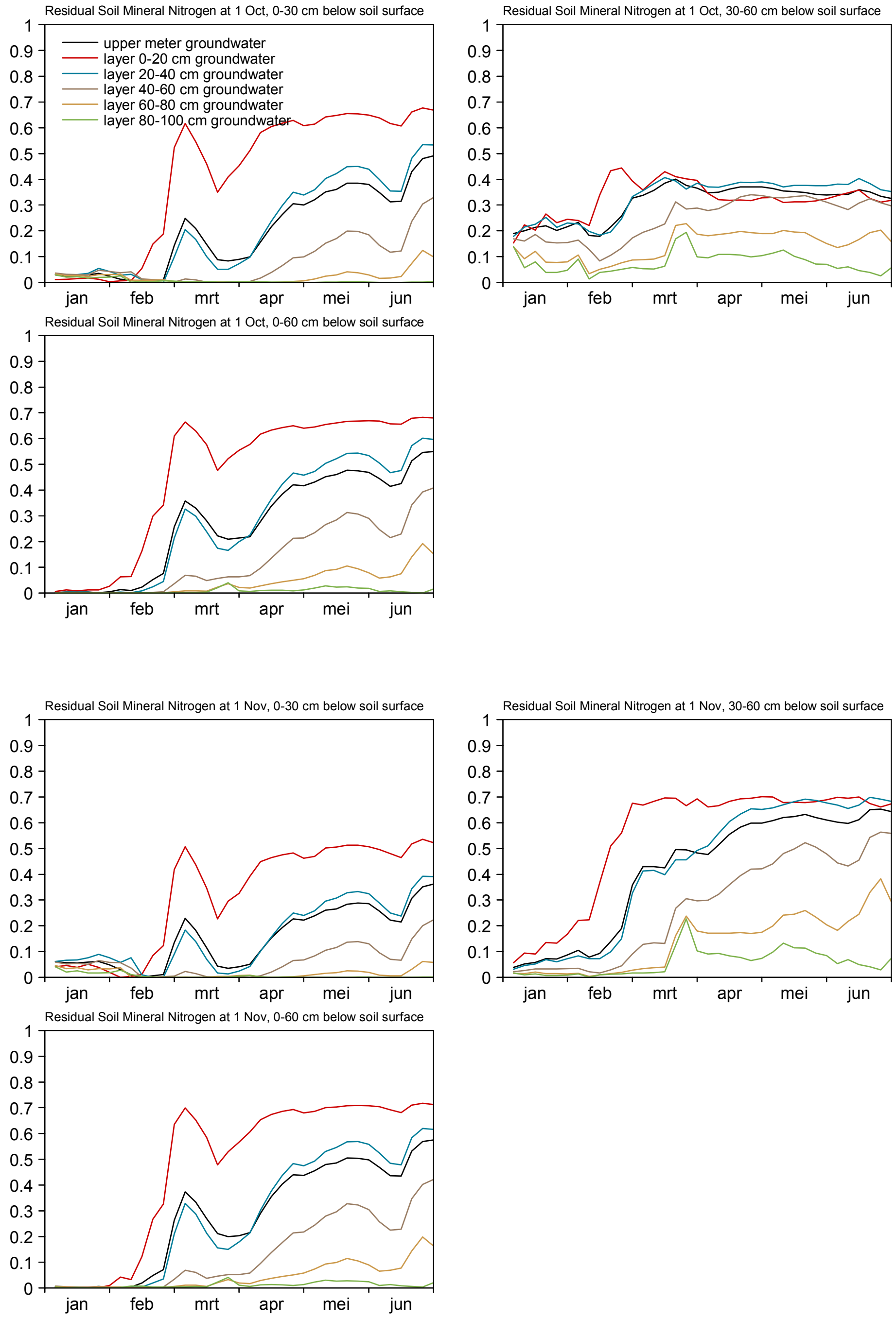


*Figure III.5.* *Correlation coefficient between different times and depths of nitrate sampling in the groundwater and different depths of residual soil mineral nitrogen at 1 October and 1 November (All simulated).*

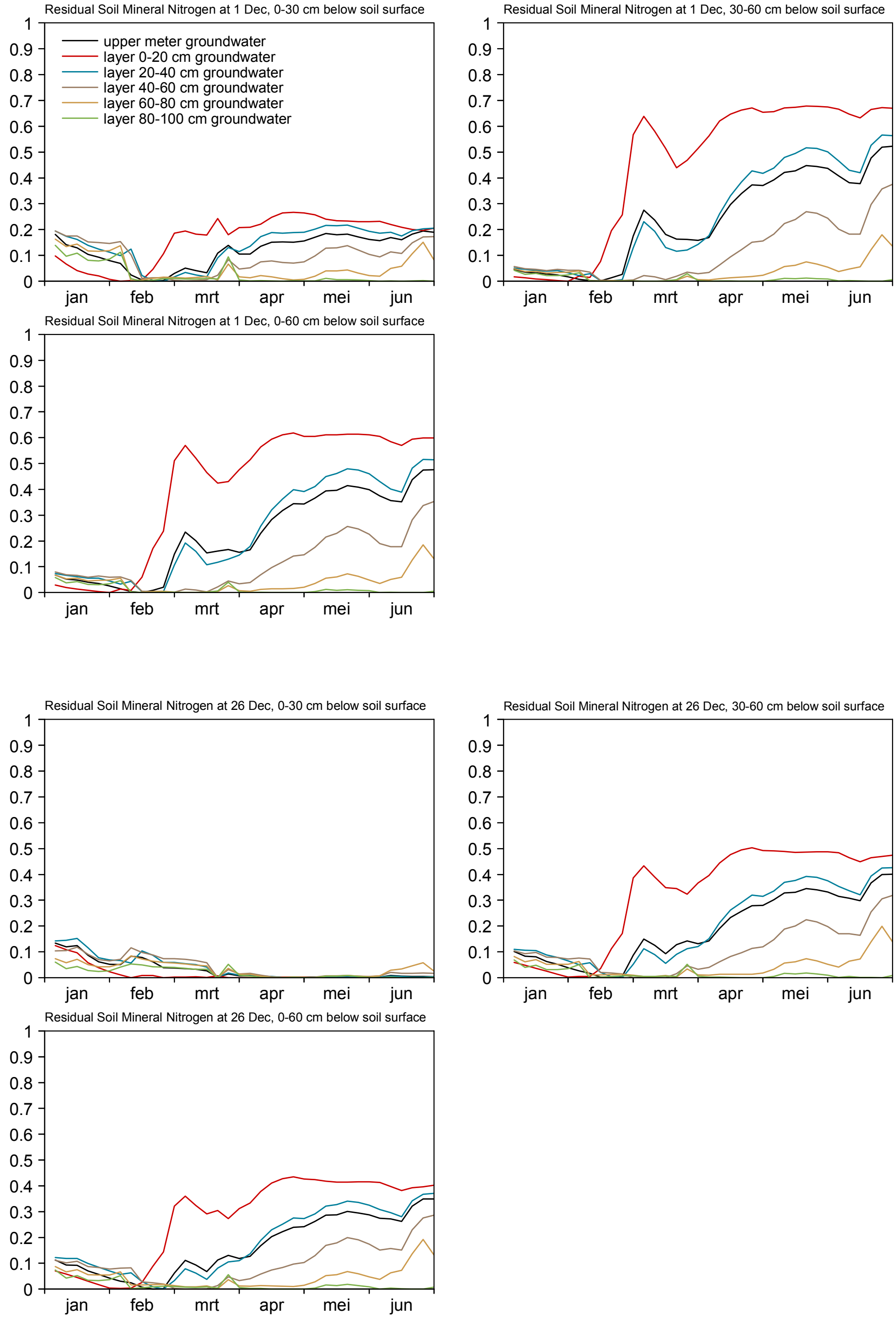


*Figure III.6. Correlation coefficient between different times and depths of nitrate sampling in the groundwater and different depths of residual soil mineral nitrogen at 1 December and 26 December (All simulated).*

## D. Vredepeel maize

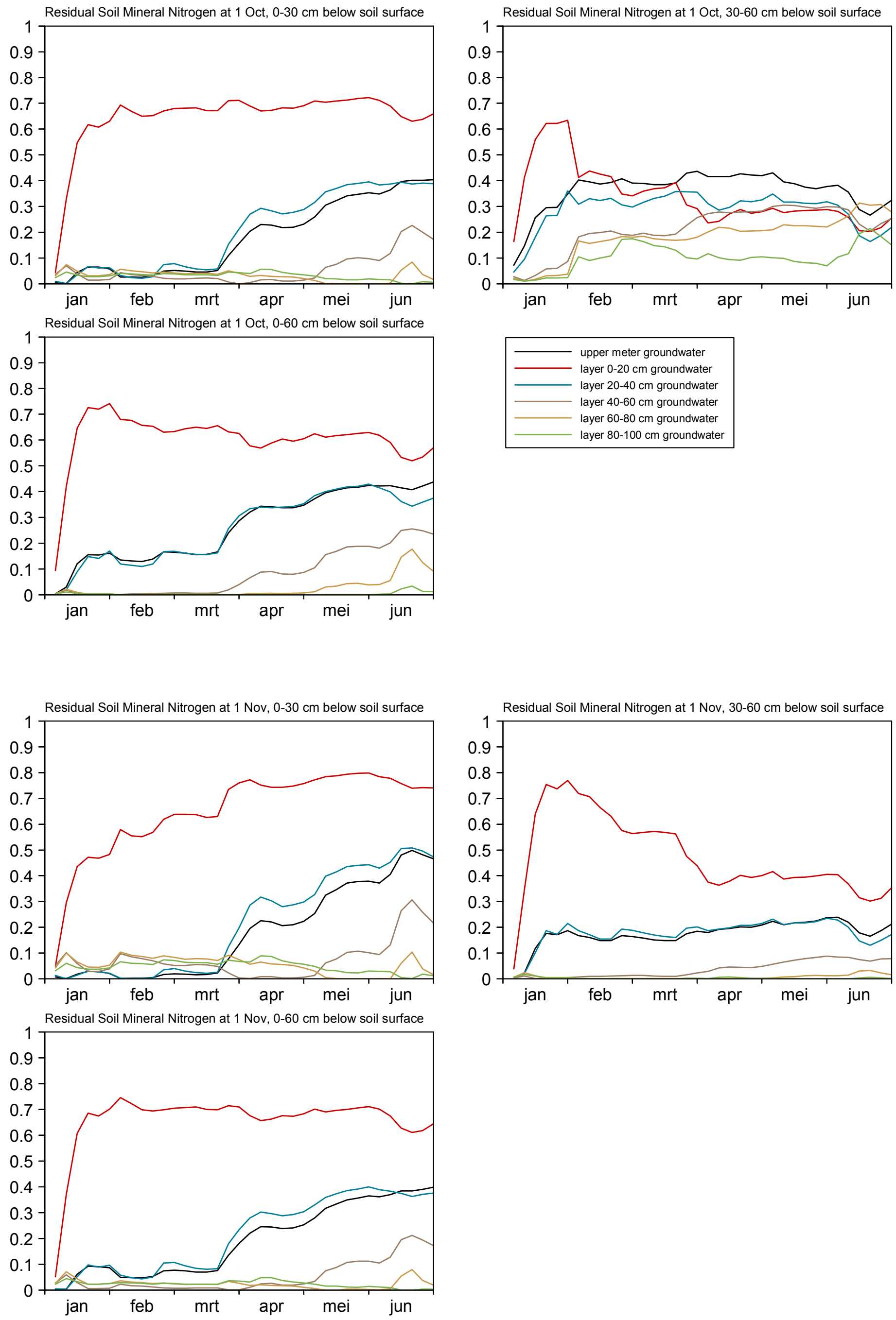


*Figure III.7. Correlation coefficient between different times and depths of nitrate sampling in the groundwater and different depths of residual soil mineral nitrogen at 1 October and 1 November (All simulated).*

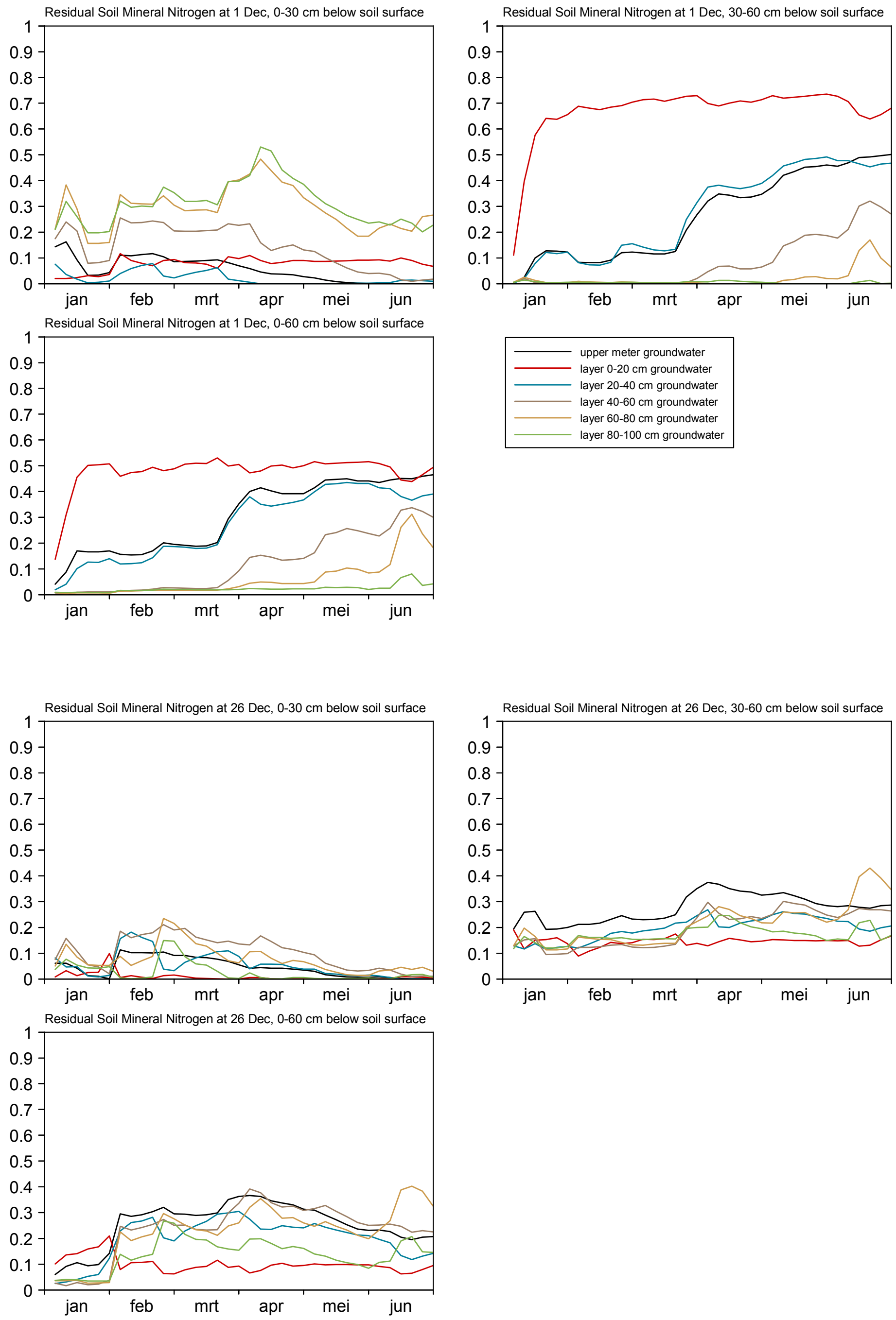


*Figure III.8. Correlation coefficient between different times and depths of nitrate sampling in the groundwater and different depths of residual soil mineral nitrogen at 1 December and 26 December (All simulated).*

# Appendix IV.
# ANIMO Simulation results: values of nitrate and $N_{min}$

This is an appendix to Chapter 8.

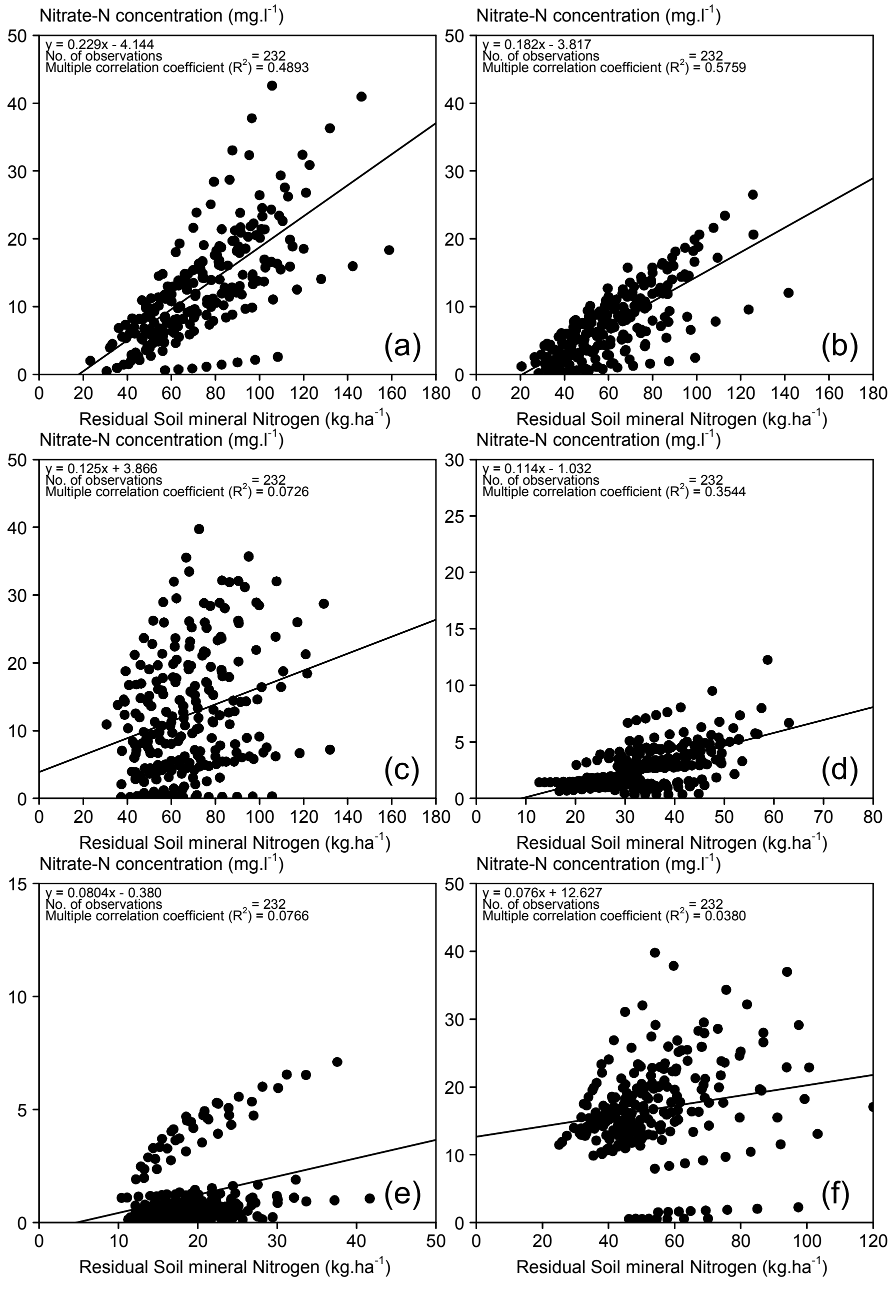


*Figure IV.1. Fit between residual soil mineral nitrogen at 1 December at 0-100 cm below soil surface and nitrate-N concentration at 1 April in the upper meter of the groundwater for Cranendonck grassland variant reference (a), Cranendonck grassland variant wet (b), Cranendonck grassland variant dry (c), Ruurlo grassland variant reference (d), Ruurlo grassland variant wet (e) and Ruurlo grassland variant dry (f) (All simulated).*

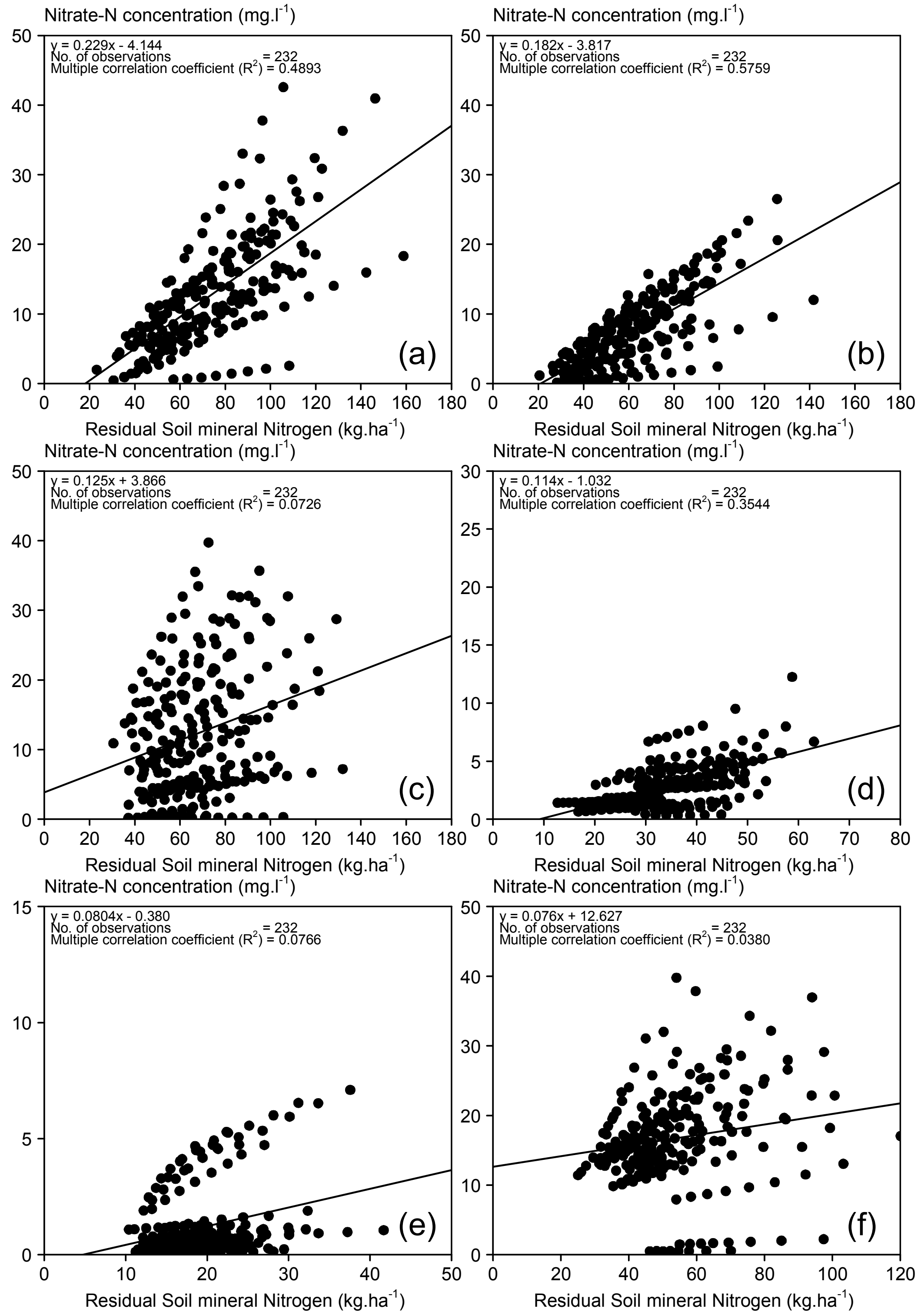


*Figure IV.2. Fit between residual soil mineral nitrogen at 1 December at 0-100 cm below soil surface and nitrate-N concentration at 1 April in the upper meter of the groundwater for Cranendonck maize variant reference (a), Cranendonck maize variant wet (b), Cranendonck maize variant dry (c), Vredepeel maize variant reference (d), Vredepeel maize variant wet (e) and Vredepeel maize variant dry (f) (All simulated).*

# Appendix V.
## Farm configurations for simulations in Chapter 10

*Characteristics and results of all 80 calculated farm situations (part 1).*

| Naam | Soil type | milk per ha (kg/ha) | quota (kg) | Area (ha) | N-application grassland (kg/ha) | % maïze | Area maize (ha) | Area grassland (ha) | % only cutting | area only cutting (ha) | grazing system | milk per cow (kg/year) | # cows | N-KAS grassland (kg/ha) | Total N in Slurry | Active N in slurry (kg/ha) | Total N applied on grassland (kg/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| plan01 | Zand VII | 10000 | 500000 | 50,0 | 250 | 15% | 7,5 | 42,5 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 173,0 | 145,5 | 78,0 | 318,5 |
| plan02 | Zand VII | 10000 | 500000 | 50,0 | 250 | 15% | 7,5 | 42,5 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 176,0 | 141,4 | 74,0 | 317,4 |
| plan03 | Zand VII | 10000 | 500000 | 50,0 | 250 | 15% | 7,5 | 42,5 | 0% | 0,0 | Sumf | 8000 | 62,5 | 130,0 | 225,7 | 121,0 | 355,7 |
| plan04 | Zand VII | 10000 | 500000 | 50,0 | 250 | 15% | 7,5 | 42,5 | 10% | 4,3 | B4+4.5 | 8000 | 62,5 | 173,0 | 145,2 | 77,0 | 318,2 |
| plan05 | Zand VII | 10000 | 500000 | 50,0 | 250 | 15% | 7,5 | 42,5 | 10% | 4,3 | B4+8 | 8000 | 62,5 | 176,0 | 141,5 | 74,0 | 317,5 |
| plan06 | Zand VII | 10000 | 500000 | 50,0 | 250 | 25% | 12,5 | 37,5 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 173,0 | 146,3 | 77,0 | 319,3 |
| plan07 | Zand VII | 10000 | 500000 | 50,0 | 250 | 25% | 12,5 | 37,5 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 175,0 | 144,2 | 75,0 | 319,2 |
| plan08 | Zand VII | 10000 | 500000 | 50,0 | 250 | 25% | 12,5 | 37,5 | 0% | 0,0 | Sumf | 8000 | 62,5 | 125,0 | 235,9 | 125,0 | 360,9 |
| plan09 | Zand VII | 10000 | 500000 | 50,0 | 250 | 25% | 12,5 | 37,5 | 10% | 3,8 | B4+4.5 | 8000 | 62,5 | 173,0 | 147,1 | 78,0 | 320,1 |
| plan10 | Zand VII | 10000 | 500000 | 50,0 | 250 | 25% | 12,5 | 37,5 | 10% | 3,8 | B4+8 | 8000 | 62,5 | 176,0 | 144,1 | 75,0 | 320,1 |
| plan11 | Zand VII | 10000 | 500000 | 50,0 | 350 | 15% | 7,5 | 42,5 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 263,0 | 159,6 | 87,0 | 422,6 |
| plan12 | Zand VII | 10000 | 500000 | 50,0 | 350 | 15% | 7,5 | 42,5 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 267,0 | 154,7 | 83,0 | 421,7 |
| plan13 | Zand VII | 10000 | 500000 | 50,0 | 350 | 15% | 7,5 | 42,5 | 0% | 0,0 | Sumf | 8000 | 62,5 | 214,0 | 248,6 | 136,0 | 462,6 |
| plan14 | Zand VII | 10000 | 500000 | 50,0 | 350 | 15% | 7,5 | 42,5 | 10% | 4,3 | B4+4.5 | 8000 | 62,5 | 263,0 | 159,2 | 87,0 | 422,2 |
| plan15 | Zand VII | 10000 | 500000 | 50,0 | 350 | 15% | 7,5 | 42,5 | 10% | 4,3 | B4+8 | 8000 | 62,5 | 267,0 | 154,9 | 83,0 | 421,9 |
| plan16 | Zand VII | 10000 | 500000 | 50,0 | 350 | 25% | 12,5 | 37,5 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 263,0 | 161,1 | 88,0 | 424,1 |
| plan17 | Zand VII | 10000 | 500000 | 50,0 | 350 | 25% | 12,5 | 37,5 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 265,0 | 158,4 | 85,0 | 423,4 |
| plan18 | Zand VII | 10000 | 500000 | 50,0 | 350 | 25% | 12,5 | 37,5 | 0% | 0,0 | Sumf | 8000 | 62,5 | 209,0 | 260,3 | 141,0 | 469,3 |
| plan19 | Zand VII | 10000 | 500000 | 50,0 | 350 | 25% | 12,5 | 37,5 | 10% | 3,8 | B4+4.5 | 8000 | 62,5 | 263,0 | 160,4 | 87,0 | 423,4 |
| plan20 | Zand VII | 10000 | 500000 | 50,0 | 350 | 25% | 12,5 | 37,5 | 10% | 3,8 | B4+8 | 8000 | 62,5 | 266,0 | 158,6 | 84,0 | 424,6 |
| plan21 | Zand VII | 15000 | 500000 | 33,3 | 250 | 15% | 5,0 | 28,3 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 163,0 | 169,6 | 85,0 | 332,6 |
| plan22 | Zand VII | 15000 | 500000 | 33,3 | 250 | 15% | 5,0 | 28,3 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 156,0 | 185,1 | 94,0 | 341,1 |
| plan23 | Zand VII | 15000 | 500000 | 33,3 | 250 | 15% | 5,0 | 28,3 | 0% | 0,0 | Sumf | 8000 | 62,5 | 101,0 | 291,1 | 150,0 | 392,1 |
| plan24 | Zand VII | 15000 | 500000 | 33,3 | 250 | 15% | 5,0 | 28,3 | 10% | 2,8 | B4+4.5 | 8000 | 62,5 | 165,0 | 169,1 | 85,0 | 334,1 |
| plan25 | Zand VII | 15000 | 500000 | 33,3 | 250 | 15% | 5,0 | 28,3 | 10% | 2,8 | B4+8 | 8000 | 62,5 | 157,0 | 184,1 | 94,0 | 341,1 |
| plan26 | Zand VII | 15000 | 500000 | 33,3 | 250 | 25% | 8,3 | 25,0 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 181,0 | 147,1 | 70,0 | 328,1 |

*Continued table (part 1).*

| Naam | Soil type | milk per ha (kg/ha) | quota (kg) | Area (ha) | N-application grassland (kg/ha) | % maïze | Area maize (ha) | Area grassland (ha) | % only cutting | area only cutting (ha) | grazing system | milk per cow (kg/year) | # cows | N-KAS grassland (kg/ha) | Total N in Slurry | Active N in slurry (kg/ha) | Total N applied on grassland (kg/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| plan27 | Zand VII | 15000 | 500000 | 33,3 | 250 | 25% | 8,3 | 25,0 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 168,0 | 168,8 | 82,0 | 336,8 |
| plan28 | Zand VII | 15000 | 500000 | 33,3 | 250 | 25% | 8,3 | 25,0 | 0% | 0,0 | Sumf | 8000 | 62,5 | | | | |
| plan29 | Zand VII | 15000 | 500000 | 33,3 | 250 | 25% | 8,3 | 25,0 | 10% | 2,5 | B4+4.5 | 8000 | 62,5 | | | | |
| plan30 | Zand VII | 15000 | 500000 | 33,3 | 250 | 25% | 8,3 | 25,0 | 10% | 2,5 | B4+8 | 8000 | 62,5 | 168,0 | 168,5 | 82,0 | 336,5 |
| plan31 | Zand VII | 15000 | 500000 | 33,3 | 350 | 15% | 5,0 | 28,3 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 250,0 | 191,6 | 100,0 | 441,6 |
| plan32 | Zand VII | 15000 | 500000 | 33,3 | 350 | 15% | 5,0 | 28,3 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 238,0 | 211,9 | 113,0 | 449,9 |
| plan33 | Zand VII | 15000 | 500000 | 33,3 | 350 | 15% | 5,0 | 28,3 | 0% | 0,0 | Sumf | 8000 | 62,5 | 178,0 | 324,5 | 172,0 | 502,5 |
| plan34 | Zand VII | 15000 | 500000 | 33,3 | 350 | 15% | 5,0 | 28,3 | 10% | 2,8 | B4+4.5 | 8000 | 62,5 | 250,0 | 191,6 | 100,0 | 441,6 |
| plan35 | Zand VII | 15000 | 500000 | 33,3 | 350 | 15% | 5,0 | 28,3 | 10% | 2,8 | B4+8 | 8000 | 62,5 | 239,0 | 210,1 | 111,0 | 449,1 |
| plan36 | Zand VII | 15000 | 500000 | 33,3 | 350 | 25% | 8,3 | 25,0 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 267,0 | 167,0 | 83,0 | 434,0 |
| plan37 | Zand VII | 15000 | 500000 | 33,3 | 350 | 25% | 8,3 | 25,0 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 253,0 | 190,9 | 97,0 | 443,9 |
| plan38 | Zand VII | 15000 | 500000 | 33,3 | 350 | 25% | 8,3 | 25,0 | 0% | 0,0 | Sumf | 8000 | 62,5 | 185,0 | 319,1 | 165,0 | 504,1 |
| plan39 | Zand VII | 15000 | 500000 | 33,3 | 350 | 25% | 8,3 | 25,0 | 10% | 2,5 | B4+4.5 | 8000 | 62,5 | 268,0 | 167,0 | 82,0 | 435,0 |
| plan40 | Zand VII | 15000 | 500000 | 33,3 | 350 | 25% | 8,3 | 25,0 | 10% | 2,5 | B4+8 | 8000 | 62,5 | 254,0 | 189,7 | 96,0 | 443,7 |
| plan41 | Zand IV | 10000 | 500000 | 50,0 | 250 | 15% | 7,5 | 42,5 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 175,0 | 141,6 | 75,0 | 316,6 |
| plan42 | Zand IV | 10000 | 500000 | 50,0 | 250 | 15% | 7,5 | 42,5 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 179,0 | 137,4 | 71,0 | 316,4 |
| plan43 | Zand IV | 10000 | 500000 | 50,0 | 250 | 15% | 7,5 | 42,5 | 0% | 0,0 | Sumf | 8000 | 62,5 | 134,0 | 217,9 | 116,0 | 351,9 |
| plan44 | Zand IV | 10000 | 500000 | 50,0 | 250 | 15% | 7,5 | 42,5 | 10% | 4,3 | B4+4.5 | 8000 | 62,5 | 176,0 | 141,2 | 75,0 | 317,2 |
| plan45 | Zand IV | 10000 | 500000 | 50,0 | 250 | 15% | 7,5 | 42,5 | 10% | 4,3 | B4+8 | 8000 | 62,5 | 179,0 | 137,4 | 71,0 | 316,4 |
| plan46 | Zand IV | 10000 | 500000 | 50,0 | 250 | 25% | 12,5 | 37,5 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 174,0 | 144,7 | 76,0 | 318,7 |
| plan47 | Zand IV | 10000 | 500000 | 50,0 | 250 | 25% | 12,5 | 37,5 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 177,0 | 142,3 | 73,0 | 319,3 |
| plan48 | Zand IV | 10000 | 500000 | 50,0 | 250 | 25% | 12,5 | 37,5 | 0% | 0,0 | Sumf | 8000 | 62,5 | 128,0 | 210,0 | 122,0 | 338,0 |
| plan49 | Zand IV | 10000 | 500000 | 50,0 | 250 | 25% | 12,5 | 37,5 | 10% | 3,8 | B4+4.5 | 8000 | 62,5 | 174,0 | 144,5 | 76,0 | 318,5 |
| plan50 | Zand IV | 10000 | 500000 | 50,0 | 250 | 25% | 12,5 | 37,5 | 10% | 3,8 | B4+8 | 8000 | 62,5 | 177,0 | 142,2 | 73,0 | 319,2 |
| plan51 | Zand IV | 10000 | 500000 | 50,0 | 350 | 15% | 7,5 | 42,5 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 265,0 | 155,0 | 84,0 | 420,0 |
| plan52 | Zand IV | 10000 | 500000 | 50,0 | 350 | 15% | 7,5 | 42,5 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 270,0 | 149,9 | 80,0 | 419,9 |

*Continued table (part 1).*

| Naam | Soil type | milk per ha (kg/ha) | quota (kg) | Area (ha) | N-application grassland (kg/ha) | % maïze | Area maize (ha) | Area grassland (ha) | % only cutting | area only cutting (ha) | grazing system | milk per cow (kg/year) | # cows | N-KAS grassland (kg/ha) | Total N in Slurry | Active N in slurry (kg/ha) | Total N applied on grassland (kg/ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| plan53 | Zand IV | 10000 | 500000 | 50,0 | 350 | 15% | 7,5 | 42,5 | 0% | 0,0 | Sumf | 8000 | 62,5 | 279,0 | 241,2 | 131,0 | 520,2 |
| plan54 | Zand IV | 10000 | 500000 | 50,0 | 350 | 15% | 7,5 | 42,5 | 10% | 4,3 | B4+4.5 | 8000 | 62,5 | 266,0 | 155,0 | 84,0 | 421,0 |
| plan55 | Zand IV | 10000 | 500000 | 50,0 | 350 | 15% | 7,5 | 42,5 | 10% | 4,3 | B4+8 | 8000 | 62,5 | 270,0 | 150,2 | 80,0 | 420,2 |
| plan56 | Zand IV | 10000 | 500000 | 50,0 | 350 | 25% | 12,5 | 37,5 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 263,0 | 160,3 | 87,0 | 423,3 |
| plan57 | Zand IV | 10000 | 500000 | 50,0 | 350 | 25% | 12,5 | 37,5 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 267,0 | 156,1 | 83,0 | 423,1 |
| plan58 | Zand IV | 10000 | 500000 | 50,0 | 350 | 25% | 12,5 | 37,5 | 0% | 0,0 | Sumf | 8000 | 62,5 | 211,0 | 256,0 | 139,0 | 467,0 |
| plan59 | Zand IV | 10000 | 500000 | 50,0 | 350 | 25% | 12,5 | 37,5 | 10% | 3,8 | B4+4.5 | 8000 | 62,5 | 264,0 | 160,1 | 86,0 | 424,1 |
| plan60 | Zand IV | 10000 | 500000 | 50,0 | 350 | 25% | 12,5 | 37,5 | 10% | 3,8 | B4+8 | 8000 | 62,5 | 267,0 | 156,5 | 83,0 | 423,5 |
| plan61 | Zand IV | 15000 | 500000 | 33,3 | 250 | 15% | 5,0 | 28,3 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 150,0 | 192,7 | 100,0 | 342,7 |
| plan62 | Zand IV | 15000 | 500000 | 33,3 | 250 | 15% | 5,0 | 28,3 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 146,0 | 199,3 | 104,0 | 345,3 |
| plan63 | Zand IV | 15000 | 500000 | 33,3 | 250 | 15% | 5,0 | 28,3 | 0% | 0,0 | Sumf | 8000 | 62,5 | 84,0 | 314,8 | 166,0 | 398,8 |
| plan64 | Zand IV | 15000 | 500000 | 33,3 | 250 | 15% | 5,0 | 28,3 | 10% | 2,8 | B4+4.5 | 8000 | 62,5 | 149,0 | 193,3 | 101,0 | 342,3 |
| plan65 | Zand IV | 15000 | 500000 | 33,3 | 250 | 15% | 5,0 | 28,3 | 10% | 2,8 | B4+8 | 8000 | 62,5 | 146,0 | 199,4 | 104,0 | 345,4 |
| plan66 | Zand IV | 15000 | 500000 | 33,3 | 250 | 25% | 8,3 | 25,0 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 162,0 | 176,3 | 88,0 | 338,3 |
| plan67 | Zand IV | 15000 | 500000 | 33,3 | 250 | 25% | 8,3 | 25,0 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 151,0 | 193,6 | 98,0 | 344,6 |
| plan68 | Zand IV | 15000 | 500000 | 33,3 | 250 | 25% | 8,3 | 25,0 | 0% | 0,0 | Sumf | 8000 | 62,5 | 90,0 | 311,0 | 160,0 | 401,0 |
| plan69 | Zand IV | 15000 | 500000 | 33,3 | 250 | 25% | 8,3 | 25,0 | 10% | 2,5 | B4+4.5 | 8000 | 62,5 | 161,0 | 177,7 | 80,0 | 338,7 |
| plan70 | Zand IV | 15000 | 500000 | 33,3 | 250 | 25% | 8,3 | 25,0 | 10% | 2,5 | B4+8 | 8000 | 62,5 | 151,0 | 194,2 | 98,0 | 345,2 |
| plan71 | Zand IV | 15000 | 500000 | 33,3 | 350 | 15% | 5,0 | 28,3 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 228,0 | 224,2 | 122,0 | 452,2 |
| plan72 | Zand IV | 15000 | 500000 | 33,3 | 350 | 15% | 5,0 | 28,3 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 233,0 | 218,2 | 117,0 | 451,2 |
| plan73 | Zand IV | 15000 | 500000 | 33,3 | 350 | 15% | 5,0 | 28,3 | 0% | 0,0 | Sumf | 8000 | 62,5 | 154,0 | 359,3 | 196,0 | 513,3 |
| plan74 | Zand IV | 15000 | 500000 | 33,3 | 350 | 15% | 5,0 | 28,3 | 10% | 2,8 | B4+4.5 | 8000 | 62,5 | 227,0 | 225,7 | 123,0 | 452,7 |
| plan75 | Zand IV | 15000 | 500000 | 33,3 | 350 | 15% | 5,0 | 28,3 | 10% | 2,8 | B4+8 | 8000 | 62,5 | 233,0 | 218,5 | 117,0 | 451,5 |
| plan76 | Zand IV | 15000 | 500000 | 33,3 | 350 | 25% | 8,3 | 25,0 | 0% | 0,0 | B4+4.5 | 8000 | 62,5 | 244,0 | 203,5 | 106,0 | 447,5 |
| plan77 | Zand IV | 15000 | 500000 | 33,3 | 350 | 25% | 8,3 | 25,0 | 0% | 0,0 | B4+8 | 8000 | 62,5 | 231,0 | 224,3 | 119,0 | 455,3 |
| plan78 | Zand IV | 15000 | 500000 | 33,3 | 350 | 25% | 8,3 | 25,0 | 0% | 0,0 | Sumf | 8000 | 62,5 | 159,0 | 357,8 | 197,0 | 516,8 |
| plan79 | Zand IV | 15000 | 500000 | 33,3 | 350 | 25% | 8,3 | 25,0 | 10% | 2,5 | B4+4.5 | 8000 | 62,5 | 243,0 | 204,3 | 107,0 | 447,3 |
| plan80 | Zand IV | 15000 | 500000 | 33,3 | 350 | 25% | 8,3 | 25,0 | 10% | 2,5 | B4+8 | 8000 | 62,5 | 230,0 | 226,3 | 120,0 | 456,3 |

*Characteristics and results of all 80 calculated farm situations (part 2).*

| Naam | Soil type | milk per ha (kg/ha) | Area (ha) | N-application grassland (kg/ha) | % maïze | Area grassland (ha) | % only cutting | grazing system | # cows | N-surplus farm level | MINAS-N-surplus farm level | N-surplus grazed grassland | N-min grazed grassland | N-surplus grassland for cutting | N-min grassland for cutting | N-surplus maize land | N-min maïze land |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| plan01 | Zand VII | 10000 | 50,0 | 250 | 15% | 42,5 | 0% | B4+4.5 | 62,5 | 163 | 107 | 148 | 56 | | | 97 | 112 |
| plan02 | Zand VII | 10000 | 50,0 | 250 | 15% | 42,5 | 0% | B4+8 | 62,5 | 152 | 93 | 137 | 55 | | | 94 | 112 |
| plan03 | Zand VII | 10000 | 50,0 | 250 | 15% | 42,5 | 0% | Sumf | 62,5 | 134 | 78 | | | 103 | 32 | 104 | 112 |
| plan04 | Zand VII | 10000 | 50,0 | 250 | 15% | 42,5 | 10% | B4+4.5 | 62,5 | 165 | 109 | 157 | 59 | 88 | 32 | 98 | 112 |
| plan05 | Zand VII | 10000 | 50,0 | 250 | 15% | 42,5 | 10% | B4+8 | 62,5 | 153 | 93 | 144 | 57 | 80 | 32 | 94 | 112 |
| plan06 | Zand VII | 10000 | 50,0 | 250 | 25% | 37,5 | 0% | B4+4.5 | 62,5 | 169 | 112 | 162 | 60 | | | 101 | 112 |
| plan07 | Zand VII | 10000 | 50,0 | 250 | 25% | 37,5 | 0% | B4+8 | 62,5 | 157 | 96 | 149 | 58 | | | 96 | 112 |
| plan08 | Zand VII | 10000 | 50,0 | 250 | 25% | 37,5 | 0% | Sumf | 62,5 | 138 | 80 | | | 108 | 32 | 106 | 112 |
| plan09 | Zand VII | 10000 | 50,0 | 250 | 25% | 37,5 | 10% | B4+4.5 | 62,5 | 172 | 115 | 173 | 63 | 96 | 32 | 102 | 112 |
| plan10 | Zand VII | 10000 | 50,0 | 250 | 25% | 37,5 | 10% | B4+8 | 62,5 | 158 | 97 | 156 | 60 | 86 | 32 | 97 | 112 |
| plan11 | Zand VII | 10000 | 50,0 | 350 | 15% | 42,5 | 0% | B4+4.5 | 62,5 | 216 | 161 | 209 | 68 | | | 96 | 112 |
| plan12 | Zand VII | 10000 | 50,0 | 350 | 15% | 42,5 | 0% | B4+8 | 62,5 | 203 | 148 | 196 | 66 | | | 93 | 112 |
| plan13 | Zand VII | 10000 | 50,0 | 350 | 15% | 42,5 | 0% | Sumf | 62,5 | 186 | 133 | | | 163 | 43 | 104 | 112 |
| plan14 | Zand VII | 10000 | 50,0 | 350 | 15% | 42,5 | 10% | B4+4.5 | 62,5 | 218 | 164 | 219 | 70 | 144 | 43 | 97 | 112 |
| plan15 | Zand VII | 10000 | 50,0 | 350 | 15% | 42,5 | 10% | B4+8 | 62,5 | 204 | 149 | 203 | 68 | 137 | 43 | 94 | 112 |
| plan16 | Zand VII | 10000 | 50,0 | 350 | 25% | 37,5 | 0% | B4+4.5 | 62,5 | 217 | 159 | 225 | 71 | | | 100 | 112 |
| plan17 | Zand VII | 10000 | 50,0 | 350 | 25% | 37,5 | 0% | B4+8 | 62,5 | 203 | 143 | 208 | 69 | | | 96 | 112 |
| plan18 | Zand VII | 10000 | 50,0 | 350 | 25% | 37,5 | 0% | Sumf | 62,5 | 184 | 126 | | | 168 | 43 | 107 | 112 |
| plan19 | Zand VII | 10000 | 50,0 | 350 | 25% | 37,5 | 10% | B4+4.5 | 62,5 | 218 | 161 | 235 | 74 | 152 | 43 | 101 | 112 |
| plan20 | Zand VII | 10000 | 50,0 | 350 | 25% | 37,5 | 10% | B4+8 | 62,5 | 204 | 145 | 217 | 71 | 144 | 43 | 97 | 112 |
| plan21 | Zand VII | 15000 | 33,3 | 250 | 15% | 28,3 | 0% | B4+4.5 | 62,5 | 231 | 160 | 214 | 69 | | | 122 | 112 |
| plan22 | Zand VII | 15000 | 33,3 | 250 | 15% | 28,3 | 0% | B4+8 | 62,5 | 219 | 146 | 199 | 66 | | | 119 | 112 |
| plan23 | Zand VII | 15000 | 33,3 | 250 | 15% | 28,3 | 0% | Sumf | 62,5 | 178 | 104 | | | 137 | 32 | 121 | 112 |
| plan24 | Zand VII | 15000 | 33,3 | 250 | 15% | 28,3 | 10% | B4+4.5 | 62,5 | 233 | 162 | 225 | 73 | 137 | 32 | 123 | 112 |
| plan25 | Zand VII | 15000 | 33,3 | 250 | 15% | 28,3 | 10% | B4+8 | 62,5 | 220 | 148 | 208 | 70 | 128 | 32 | 119 | 112 |
| plan26 | Zand VII | 15000 | 33,3 | 250 | 25% | 25,0 | 0% | B4+4.5 | 62,5 | 232 | 154 | 228 | 74 | | | 124 | 112 |
| plan27 | Zand VII | 15000 | 33,3 | 250 | 25% | 25,0 | 0% | B4+8 | 62,5 | 219 | 141 | 211 | 70 | | | 121 | 112 |

*Continued table (part 2).*

| Naam | Soil type | milk per ha (kg/ha) | Area (ha) | N-application grassland (kg/ha) | % maïze | Area grassland (ha) | % only cutting | grazing system | # cows | N-surplus farm level | MINAS-N-surplus farm level | N-surplus grazed grassland | N-min grazed grassland | N-surplus grassland for cutting | N-min grassland for cutting | N-surplus maize land | N-min maïze land |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| plan28 | Zand VII | 15000 | 33,3 | 250 | 25% | 25,0 | 0% | Sumf | 62,5 | 152 | 73 | | | 110 | 32 | 121 | 112 |
| plan29 | Zand VII | 15000 | 33,3 | 250 | 25% | 25,0 | 10% | B4+4.5 | 62,5 | | | | | | | | |
| plan30 | Zand VII | 15000 | 33,3 | 250 | 25% | 25,0 | 10% | B4+8 | 62,5 | 221 | 143 | 222 | 75 | 135 | 32 | 122 | 112 |
| plan31 | Zand VII | 15000 | 33,3 | 350 | 15% | 28,3 | 0% | B4+4.5 | 62,5 | 291 | 219 | 283 | 80 | | | 122 | 112 |
| plan32 | Zand VII | 15000 | 33,3 | 350 | 15% | 28,3 | 0% | B4+8 | 62,5 | 276 | 204 | 265 | 77 | | | 119 | 112 |
| plan33 | Zand VII | 15000 | 33,3 | 350 | 15% | 28,3 | 0% | Sumf | 62,5 | 233 | 159 | | | 200 | 43 | 122 | 112 |
| plan34 | Zand VII | 15000 | 33,3 | 350 | 15% | 28,3 | 10% | B4+4.5 | 62,5 | 294 | 222 | 295 | 84 | 197 | 43 | 123 | 112 |
| plan35 | Zand VII | 15000 | 33,3 | 350 | 15% | 28,3 | 10% | B4+8 | 62,5 | 278 | 205 | 275 | 81 | 190 | 43 | 120 | 112 |
| plan36 | Zand VII | 15000 | 33,3 | 350 | 25% | 25,0 | 0% | B4+4.5 | 62,5 | 286 | 208 | 299 | 85 | | | 125 | 112 |
| plan37 | Zand VII | 15000 | 33,3 | 350 | 25% | 25,0 | 0% | B4+8 | 62,5 | 271 | 192 | 278 | 82 | | | 121 | 112 |
| plan38 | Zand VII | 15000 | 33,3 | 350 | 25% | 25,0 | 0% | Sumf | 62,5 | 225 | 146 | | | 202 | 43 | 123 | 112 |
| plan39 | Zand VII | 15000 | 33,3 | 350 | 25% | 25,0 | 10% | B4+4.5 | 62,5 | 291 | 213 | 315 | 89 | 204 | 43 | 126 | 112 |
| plan40 | Zand VII | 15000 | 33,3 | 350 | 25% | 25,0 | 10% | B4+8 | 62,5 | 273 | 195 | 291 | 86 | 195 | 43 | 122 | 112 |
| plan41 | Zand IV | 10000 | 50,0 | 250 | 15% | 42,5 | 0% | B4+4.5 | 62,5 | 118 | 49 | 101 | 51 | | | 65 | 112 |
| plan42 | Zand IV | 10000 | 50,0 | 250 | 15% | 42,5 | 0% | B4+8 | 62,5 | 106 | 32 | 87 | 50 | | | 63 | 112 |
| plan43 | Zand IV | 10000 | 50,0 | 250 | 15% | 42,5 | 0% | Sumf | 62,5 | 84 | 15 | | | 51 | 33 | 71 | 112 |
| plan44 | Zand IV | 10000 | 50,0 | 250 | 15% | 42,5 | 10% | B4+4.5 | 62,5 | 119 | 50 | 109 | 53 | 35 | 33 | 66 | 112 |
| plan45 | Zand IV | 10000 | 50,0 | 250 | 15% | 42,5 | 10% | B4+8 | 62,5 | 106 | 32 | 95 | 51 | 29 | 33 | 63 | 112 |
| plan46 | Zand IV | 10000 | 50,0 | 250 | 25% | 37,5 | 0% | B4+4.5 | 62,5 | 126 | 58 | 116 | 53 | | | 68 | 112 |
| plan47 | Zand IV | 10000 | 50,0 | 250 | 25% | 37,5 | 0% | B4+8 | 62,5 | 113 | 40 | 100 | 52 | | | 65 | 112 |
| plan48 | Zand IV | 10000 | 50,0 | 250 | 25% | 37,5 | 0% | Sumf | 62,5 | 90 | 22 | | | 57 | 33 | 73 | 112 |
| plan49 | Zand IV | 10000 | 50,0 | 250 | 25% | 37,5 | 10% | B4+4.5 | 62,5 | 126 | 58 | 124 | 56 | 42 | 33 | 69 | 112 |
| plan50 | Zand IV | 10000 | 50,0 | 250 | 25% | 37,5 | 10% | B4+8 | 62,5 | 114 | 41 | 109 | 54 | 35 | 33 | 65 | 112 |
| plan51 | Zand IV | 10000 | 50,0 | 350 | 15% | 42,5 | 0% | B4+4.5 | 62,5 | 160 | 97 | 150 | 63 | | | 64 | 112 |
| plan52 | Zand IV | 10000 | 50,0 | 350 | 15% | 42,5 | 0% | B4+8 | 62,5 | 149 | 83 | 138 | 62 | | | 62 | 112 |
| plan53 | Zand IV | 10000 | 50,0 | 350 | 15% | 42,5 | 0% | Sumf | 62,5 | 121 | 59 | | | 93 | 45 | 69 | 112 |
| plan54 | Zand IV | 10000 | 50,0 | 350 | 15% | 42,5 | 10% | B4+4.5 | 62,5 | 161 | 98 | 159 | 65 | 76 | 45 | 64 | 112 |

*Continued table (part 2).*

| Naam | Soil type | milk per ha (kg/ha) | Area (ha) | N-application grassland (kg/ha) | % maïze | Area grassland (ha) | % only cutting | grazing system | # cows | N-surplus farm level | MINAS-N-surplus farm level | N-surplus grazed grassland | N-min grazed grassland | N-surplus grassland for cutting | N-min grassland for cutting | N-surplus maize land | N-min maïze land |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| plan55 | Zand IV | 10000 | 50,0 | 350 | 15% | 42,5 | 10% | B4+8 | 62,5 | 149 | 82 | 145 | 64 | 70 | 45 | 61 | 112 |
| plan56 | Zand IV | 10000 | 50,0 | 350 | 25% | 37,5 | 0% | B4+4.5 | 62,5 | 164 | 99 | 166 | 66 | | | 67 | 112 |
| plan57 | Zand IV | 10000 | 50,0 | 350 | 25% | 37,5 | 0% | B4+8 | 62,5 | 152 | 84 | 151 | 64 | | | 64 | 112 |
| plan58 | Zand IV | 10000 | 50,0 | 350 | 25% | 37,5 | 0% | Sumf | 62,5 | 124 | 59 | | | 100 | 45 | 71 | 112 |
| plan59 | Zand IV | 10000 | 50,0 | 350 | 25% | 37,5 | 10% | B4+4.5 | 62,5 | 164 | 100 | 176 | 68 | 84 | 45 | 67 | 112 |
| plan60 | Zand IV | 10000 | 50,0 | 350 | 25% | 37,5 | 10% | B4+8 | 62,5 | 152 | 84 | 160 | 66 | 77 | 45 | 64 | 112 |
| plan61 | Zand IV | 15000 | 33,3 | 250 | 15% | 28,3 | 0% | B4+4.5 | 62,5 | 190 | 116 | 169 | 60 | | | 90 | 112 |
| plan62 | Zand IV | 15000 | 33,3 | 250 | 15% | 28,3 | 0% | B4+8 | 62,5 | 177 | 99 | 154 | 58 | | | 85 | 112 |
| plan63 | Zand IV | 15000 | 33,3 | 250 | 15% | 28,3 | 0% | Sumf | 62,5 | 137 | 62 | | | 93 | 33 | 89 | 112 |
| plan64 | Zand IV | 15000 | 33,3 | 250 | 15% | 28,3 | 10% | B4+4.5 | 62,5 | 190 | 117 | 178 | 63 | 90 | 33 | 90 | 112 |
| plan65 | Zand IV | 15000 | 33,3 | 250 | 15% | 28,3 | 10% | B4+8 | 62,5 | 177 | 99 | 163 | 61 | 79 | 33 | 86 | 112 |
| plan66 | Zand IV | 15000 | 33,3 | 250 | 25% | 25,0 | 0% | B4+4.5 | 62,5 | 192 | 112 | 183 | 64 | | | 93 | 112 |
| plan67 | Zand IV | 15000 | 33,3 | 250 | 25% | 25,0 | 0% | B4+8 | 62,5 | 180 | 100 | 168 | 61 | | | 88 | 112 |
| plan68 | Zand IV | 15000 | 33,3 | 250 | 25% | 25,0 | 0% | Sumf | 62,5 | 137 | 56 | | | 96 | 33 | 90 | 112 |
| plan69 | Zand IV | 15000 | 33,3 | 250 | 25% | 25,0 | 10% | B4+4.5 | 62,5 | 194 | 115 | 195 | 67 | 98 | 33 | 93 | 112 |
| plan70 | Zand IV | 15000 | 33,3 | 250 | 25% | 25,0 | 10% | B4+8 | 62,5 | 180 | 100 | 177 | 64 | 88 | 33 | 89 | 112 |
| plan71 | Zand IV | 15000 | 33,3 | 350 | 15% | 28,3 | 0% | B4+4.5 | 62,5 | 242 | 167 | 228 | 72 | | | 90 | 112 |
| plan72 | Zand IV | 15000 | 33,3 | 350 | 15% | 28,3 | 0% | B4+8 | 62,5 | 224 | 145 | 209 | 70 | | | 83 | 112 |
| plan73 | Zand IV | 15000 | 33,3 | 350 | 15% | 28,3 | 0% | Sumf | 62,5 | 181 | 104 | | | 141 | 45 | 88 | 112 |
| plan74 | Zand IV | 15000 | 33,3 | 350 | 15% | 28,3 | 10% | B4+4.5 | 62,5 | 243 | 169 | 238 | 75 | 142 | 45 | 91 | 112 |
| plan75 | Zand IV | 15000 | 33,3 | 350 | 15% | 28,3 | 10% | B4+8 | 62,5 | 224 | 145 | 218 | 73 | 123 | 45 | 83 | 112 |
| plan76 | Zand IV | 15000 | 33,3 | 350 | 25% | 25,0 | 0% | B4+4.5 | 62,5 | 238 | 158 | 244 | 76 | | | 92 | 112 |
| plan77 | Zand IV | 15000 | 33,3 | 350 | 25% | 25,0 | 0% | B4+8 | 62,5 | 226 | 145 | 228 | 73 | | | 87 | 112 |
| plan78 | Zand IV | 15000 | 33,3 | 350 | 25% | 25,0 | 0% | Sumf | 62,5 | 176 | 94 | | | 145 | 45 | 89 | 112 |
| plan79 | Zand IV | 15000 | 33,3 | 350 | 25% | 25,0 | 10% | B4+4.5 | 62,5 | 240 | 160 | 256 | 79 | 149 | 45 | 93 | 112 |
| plan80 | Zand IV | 15000 | 33,3 | 350 | 25% | 25,0 | 10% | B4+8 | 62,5 | 227 | 146 | 239 | 77 | 137 | 45 | 88 | 112 |