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Schriftleitung
Prof. Dr. Folkhard Isermeyer

Geschäftsführung
Dr. Matthias Rütze
Tel. 040 · 739 62 - 247
Leuschnerstraße 91
21031 Hamburg, Germany

landbauforschung@vti.bund.de
www.vti.bund.de

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Editorial Board
Directors of vTI-Institutes

Editor in Chief
Prof. Dr. Folkhard Isermeyer

Managing Editor
Dr. Matthias Rütze
Phone + 49 - 40 · 739 62 - 247
Leuschnerstraße 91
21031 Hamburg, Germany

landbauforschung@vti.bund.de
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Ländlicher Tourismus als Chance? Möglichkeiten und Grenzen der Förderung von ländlichem Tourismus am Beispiel eines Modellvorhabens

Stefan Neumeier und Kim Pollermann*

Zusammenfassung

Tourismus als Faktor der Regionalentwicklung wird immer wieder als Option zur Entwicklung ländlicher Räume genannt. Ein 1993 initiiertes Modellvorhaben „Einkommenssicherung durch Dorftourismus" des Bundesministeriums für Ernährung, Landwirtschaft und Forsten (BMELF) hatte zum Ziel, exemplarisch in fünf peripheren ostdeutschen ländlichen Regionen touristische Konzepte zur ländlichen Entwicklung zu fördern. Die wesentlichen Inhalte der Konzepte waren dabei die Etablierung eines tragfähigen ländlichen Tourismus, wobei die Modellregionen bewusst nicht über eine besondere touristische Eignung verfügten.

Vor diesem Hintergrund widmet sich der Artikel der Frage, in wieweit eine Förderung der ländlichen Regionalentwicklung durch Tourismus in peripheren Regionen ohne entsprechende touristische Alleinstellungsmerkmale möglich ist und welche Lehren aus dem Modellvorhaben für die Ausgestaltung zukünftiger Förderungen gezogen werden können.

Als Ergebnis wird aufgezeigt, dass der ländliche Tourismus als Faktor der ländlichen Entwicklung interessante Potenziale in diesen Regionen bietet, sofern nicht nur ökonomische Aspekte als Messlatte dienen. Zwar stellten sich die ökonomischen Wirkungen im Sinne einer „Einkommenssicherung" als sehr gering heraus, demgegenüber waren jedoch positive Wirkungen im Bereich Freizeitinfrastruktur/Naherholung, eine verbesserte raumbezogene Identität sowie die Aktivierung lokaler Akteure fest zu stellen.

So kann die Beschäftigung mit ländlichem Tourismus auch in Regionen, die sich eigentlich nicht besonders für eine touristische Inwertsetzung eignen (z. B. aufgrund schlechter Erreichbarkeit, fehlender Alleinstellungsmerkmale), Impulse zur ländlichen Entwicklung geben.

Schlüsselwörter: Tourismus, Regionalentwicklung, ländlich, Förderprogramm, Modellprojekt

Abstract

Rural tourism as a chance? Opportunities and limitations for the promotion of rural tourism using the example of a pilot project

Tourism as means of regional development is consistently cited as one option for developing rural regions. In this spirit, the German Ministry for Food, Agriculture and Forestry initiated the model project "income maintenance through village tourism" in 1993. The main aim of the model project was to foster sustainable concepts of rural development taking five eastern German rural regions as an example. The crux of the project was to establish stable rural tourism in rural regions without unique tourist attractions.

Against this background the article addresses the question of the extent to which regional development can be brought forward by tourism in regions without any unique tourist selling propositions and what can be learnt from the model project for the shaping of similar support activities in the future.

As result it is shown that the success of rural tourism should not be considered from a purely economic perspective and reveals that tourism, as factor of rural development, has the potential to trigger other important development impulses. Though the economic impact – in the sense of „income maintenance" -- was very small, positive impacts like leisure infrastructure/local recreation, place-related identity and the activation of local actors could be identified. Thus, so the reasoning, tourism has the potential to be used as a factor of rural development even in regions actually not very suitable for tourism such as, for example, poorly accessible peripheral regions with no unique selling propositions.

Keywords: tourism, regional development, rural, funding sheme, pilot project

* Johann Heinrich von Thünen-Institut (vTI), Bundesforschungsinstitut für Ländliche Räume, Wald und Fischerei, Institut für Ländliche Räume, Bundesallee 50, 38116 Braunschweig, Email: stefan.neumeier@vti.bund.de

1 Einleitung und Problemhintergrund

Um die Regionalentwicklung in strukturschwachen Regionen zu fördern, wird oftmals eine touristische Entwicklung als Lösungsansatz postuliert (vgl. Mundt, 2001; McAreavey und McDonagh, 2010), was sich beispielsweise auch an dem hohen Stellenwert des Tourismus in den ländlichen Entwicklungsprogrammen zeigt (z. B. das EPLR M-V (Ministerium für Landwirtschaft Umwelt und Verbraucherschutz des Landes Mecklenburg-Vorpommern, 2009)). Der Grund dafür ist, dass hier noch am ehesten Potenziale vermutet werden, um Arbeitsplätze zu schaffen und Einkommen in der Region zu erwirtschaften. Außerdem wird davon ausgegangen, dass der Tourismus positive wirtschaftliche Impulse in den ihm vor- und nachgelagerten Branchen auslöst (vgl. Benthien, 1995; Cawley und Gillmor, 2008; Deller, 2009).

Um die Nutzung diesbezüglicher Chancen für periphere Regionen in Ostdeutschland zu unterstützen, initiierte das Bundesministerium für Ernährung, Landwirtschaft und Forsten (BMELF) 1993 das Modellprojekt „Einkommenssicherung durch Dorftourismus“[1]. Grundsätzlicher Ansatz des Modellvorhabens war, am Beispiel des Dorftourismus[2] nachhaltige, tragfähige Konzepte zur ländlichen Entwicklung in Problemregionen auszuarbeiten. Die Umsetzung sollte in Eigeninitiative unter Akquirierung des bestehenden Förderangebots der Länder erfolgen, wobei eine externe Beratung finanziert, jedoch keine eigenen Fördergelder bereitgestellt wurden.

Die Auswirkungen des Modellvorhabens wurden in zwei Phasen (1995 bis 1998 und 2005 bis 2009) am Institut für Ländliche Räume[3] des Johann Heinrich von Thünen-Instituts in Braunschweig erforscht. Dazu erfolgte eine erste, zum Teil parallele Begleitforschung (vgl. Fink und Plankl 1998) sowie eine zweite, auf die langfristigen Wirkungen des Modellvorhabens fokussierte Nachuntersuchung (vgl. Neumeier et al., 2011).

Im vorliegenden Artikel wird der Aspekt „Förderung von Tourismus als Faktor der Entwicklung ländlicher Räume“ diskutiert. Das Hauptaugenmerk liegt dabei auf der Frage, in wieweit eine Förderung der Regionalentwicklung durch ländlichen Tourismus überhaupt möglich ist und welche Lehren aus dem Modellprojekt für eine optimale Ausgestaltung zukünftiger Projekte mit ähnlicher Intention gezogen werden können. Dazu werden nach einer einleitenden theoretischen Betrachtung des ländlichen Tourismus als Faktor der Regionalentwicklung (Kapitel 2) das Modellvorhaben (Kapitel 3) und das methodischen Vorgehen der Nachuntersuchung (Kapitel 4) charakterisiert. Im Anschluss daran werden ausgewählte empirische Ergebnisse zur touristischen Entwicklung in den Modellregionen vorgestellt (Kapitel 5) und darauf aufbauend Möglichkeiten und Grenzen der Förderung peripherer Regionen ohne besondere touristische Alleinstellungsmerkmale durch ländlichen Tourismus diskutiert (Kapitel 6). Nach Hinweisen, wie unter Berücksichtigung der Literatur zu Planungsprozessen, die vorhandenen Chancen am ehesten genutzt werden können (Kapitel 7), werden Schlussfolgerungen zur Ausgestaltung externer Förderungen gezogen (Kapitel 8).

2 Ländlicher Tourismus als Faktor der Regionalentwicklung

2.1 Was ist ländlicher Tourismus?

Um sich mit dem ländlichen Tourismus und dessen Beitrag zur Regionalentwicklung befassen zu können, ist es zunächst notwendig zu klären, was überhaupt unter dem Begriff „ländlicher Tourismus“ zu verstehen ist.

Dies ist kein ganz leichtes Unterfangen, da bereits die Definition des Tourismusbegriffs recht problematisch ist und verschiedene Sichtweisen dazu existieren (vgl. Johnston et. al., 2000). Im Rahmen des Artikels wird Tourismus in Anlehnung an die Definition der OECD verstanden als alle Aktivitäten von Personen, die sich für längere Zeit an Orte außerhalb ihres Arbeits-, Wohn- oder Versorgungsstandorts begeben und sich dort nicht länger als ein Jahr zu Freizeit-, Geschäfts- und anderen Zwecken aufhalten, wobei der Hauptreisezweck ein anderer ist als die Ausübung einer Tätigkeit, die vom besuchten Ort aus vergütet wird (vgl. OECD, 2002; Leser et al., 1993). In enger Auslegung zählen Berufs- und Einkaufsreiseverkehr ebenso wie Naherholung mit nicht mindestens einer Übernachtung somit nicht zum Tourismus im eigentlichen Sinn (vgl. Leser et al., 1993).

Ebenfalls schwer abzugrenzen ist, was unter „ländlichen Tourismus“ zu verstehen ist, da dieser ebenso wie die ländlichen Räume, in denen er stattfindet, sehr facettenreich ist (Lane, 1994: 9f). Am einen Ende des Spektrums von Definitionsmöglichkeiten werden unter „ländlichem Tourismus“ alle touristischen Aktivitäten verstanden, die in ländlichen Räumen stattfinden. Am anderen Ende erfolgt eine Eingrenzung auf sehr spezifische Formen bzw. Ausprägungen wie z. B. „Urlaub auf dem Bauernhof“ oder „Naturtourismus“ (vgl. Oppermann, 1996). Dabei weist

[1] Die Finanzierung erfolgte gemeinsam mit dem Wirtschaftsministerium des Bundes sowie den Wirtschafs- und Landwirtschaftsministerien der beteiligten Bundesländer.

[2] Ziel war es in den Modellregionen einen „sanften“, an die jeweiligen Gegebenheiten der Regionen angepassten ländlichen Tourismus als „Urlaub auf dem Lande“ als Pendant zu dem Modell „Urlaub auf dem Bauernhof“ zu etablieren. Der Begriff „Dorftourismus“ wurde im Modellvorhaben synonym für diesen „Urlaub auf dem Lande“ verwendet. Weder „Urlaub auf dem Lande“ noch „Dorftourismus“ wurden im Modellvorhaben selbst oder der Begleitforschung 1995 bis 1998 exakt definiert.

[3] bzw. dessen Vorgängerinstitution

Lane (1994) darauf hin, dass es aber zu einfach wäre, ländlichen Tourismus lediglich als Tourismus in ländlichen Räumen zu verstehen (Lane, 1994) und er deshalb ähnlich wie die ländlichen Räume, in denen er stattfindet, als Kontinuum zu konzeptionalisieren ist (Lane, 1994). In der Nähe zu Verdichtungsräumen weist der ländliche Tourismus z. B. urbane Charakteristika auf, basiert z. T. auch auf Naherholung und kann hohe Gästeankünfte (Tages- und Übernachtungstourismus) verzeichnen. In peripheren Regionen hingegen überwiegen andere, eher ländlich geprägte touristische Schwerpunkte und die Gästezahlen sind i. d. R. deutlich geringer, falls die Regionen keine außergewöhnlichen touristischen Alleinstellungsmerkmale aufweisen (vgl. Lane, 1994; Sharpley und Roberts, 2004). Diese Feststellungen zum Tourismus in solchen peripheren Regionen sind auch für den angestrebten „Dorftourismus" in den Modellregionen zutreffend.

Da Lanes (1994) Verständnis von ländlichem Tourismus den verschiedenen Ausprägungen touristischer Aktivitäten in ländlichen Räumen unserer Ansicht nach besser Rechnung trägt als engere Definitionen, liegt den folgenden Ausführungen Lanes (1994) Konzeptionalisierung des „ländlichen Tourismus" zugrunde.

2.2 Wie kann Tourismus zur Regionalentwicklung beitragen?

Tourismus gilt als einer der dynamischsten Wirtschaftszweige überhaupt (Garbe, 2003; Mundt, 2001). Der Aufschwung, den dieser in den letzten Jahrzehnten erfahren hat, setzt sich global gesehen in nur wenig abgeschwächter Form auch weiterhin fort. Tourismusexperten gehen auch davon aus, dass der Tourismus ein großes Potenzial besitzt, einen Beitrag zur regionalen Wirtschaftsentwicklung leisten zu können (vgl. Job et al., 2004, Wilson et al., 2001, Jensen-Butler et al., 2007). Wie Untersuchungen zum Tourismus als Faktor der Regionalentwicklung gezeigt haben, kann Tourismus in peripheren Regionen prinzipiell die Funktion eines Wachstumspols[4] übernehmen, vorausgesetzt diese Regionen eignen sich für eine touristische Inwertsetzung (vgl. Neumeier, 2002; Scherer, 2005).

Um eine periphere Region, die entsprechende touristische Potenziale besitzt, Erfolg versprechend zu erschließen, ist es notwendig, ein attraktives, zeitgemäßes und konkurrenzfähiges regionsspezifisches Tourismusprofil zu entwickeln.[5] Eine wesentliche Voraussetzung für eine langfristig erfolgreiche Tourismusentwicklung in ländlichen Räumen ist eine attraktive und intakte Landschaft (vgl. Scherer, 2005; Schemel et al., 2001). Neben den natur- und kulturlandschaftlichen Gegebenheiten einer Region sind für einen erfolgreichen Tourismus die Menge sowie die Qualität der verschiedenen Angebote des Fremdenverkehrsgewerbes, der vorhandenen Infrastruktur und die Dienstleistungsbereitschaft der Bevölkerung ausschlaggebend (vgl. Bernard, 2001; Haugland et al., 2011). Dabei ist auch zu beachten, dass potenzielle Gäste von den Leistungsträgern ein gewisses Niveau an Angebotsdifferenzierung und -diversifizierung erwarten. Das bedeutet, Regionen brauchen ein entsprechend großes Mindestangebot an touristischer Infrastruktur und Attraktivitäten, damit der Tourismus tatsächlich einen Beitrag zur regionalen Entwicklung leisten kann. Ohne dieses Mindestangebot können i. d. R. keine nennenswerten Wachstumsimpulse für die Region vom Tourismus ausgehen (Scherer, 2005).

Das bedeutet in Konsequenz aber auch, dass es nur dann Sinn macht, auf den Tourismus als Faktor der Regionalentwicklung zu setzen, falls eine Region auch entsprechend attraktive Voraussetzungen sowie eine entsprechende touristische Infra- und Suprastruktur bzw. das Potenzial, diese zu entwickeln, besitzt, die sich touristisch „vermarkten" lassen. Heimatmuseen, Gemeindecenter, Naturlehrpfade, Backhäuser, Outdoor-Schach und Kräuterspiralen, um nur einige Beispiele zu nennen, die gerade in peripheren ländlichen Regionen im Rahmen der ländlichen Entwicklung im Hinblick auf eine touristische Inwertsetzung immer wieder angedacht werden, gehören aber eher zur (intraregionalen) Naherholungsinfrastruktur. Von einem rein ökonomischen Blickwinkel aus besitzen diese nicht das Potenzial, als regionale touristische Alleinstellungsmerkmale bzw. über die Region hinausgehende „Aushängeschilder" zu fungieren und in einem signifikanten Ausmaß Gäste von außerhalb in die Region zu bringen (vgl. Neumeier et al., 2011).

Generell hat auch die Ausrichtung des Tourismus Einfluss auf die Entwicklungschancen, insbesondere muss die Ausrichtung zu den angesprochenen touristischen Zielgruppen passen.

Im Hinblick auf den Tourismus als Faktor der Regionalentwicklung für ländliche Räume weisen Benthien (1995) und Mundt (2001) außerdem einschränkend darauf hin, dass vor dem Hintergrund des zu beobachtenden sozio-

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[4] So kann Geld, das von den Touristen innerhalb einer Region ausgegeben wird, in dem Tourismus vor- und nachgelagerte Wirtschaftsbereiche fließen und das regionale ökonomische Wachstum aktivieren – vorausgesetzt die Betreiber touristischer Einrichtungen beziehen die von ihnen benötigten Waren und Dienstleistungen auf den lokalen Märkten (vgl. Lübben, 1995). Das theoretische Konzept, das hinter der wirtschaftlichen Bedeutung des Tourismus für die Regionalentwicklung als Wachstumspol steht, basiert also auf dem Grundgedanken der Import-Export-Theorie (vgl. Summers und Field, 2000, S. 21).

[5] Das Tourismusprofil sollte aus der Region selbst heraus entwickelt werden, damit es bei Einheimischen und Touristen gleichermaßen Akzeptanz findet (vgl. Benthien, 1995). Weitere Punkte, die es zu berücksichtigen gilt, finden sich z. B. bei Fink und Plankl (1998).

ökonomischen Strukturwandels in ländlichen Räumen Tourismus in der Praxis zwar lokal und individuell dazu beitragen kann, Einkommensalternativen zu eröffnen, aber nicht entsprechend flächendeckend und von derartiger makroökonomischer Bedeutung, dass er den produktiven Sektor ersetzen oder seinen Rückgang kompensieren kann (vgl. Benthien, 1995; Mundt, 2001). So erklärt Terluin zur wirtschaftlichen Entwicklung im ländlichen Raum (2003, S. 338): "The pattern of employment growth shows that tourism, which is often one of the main pillars in rural development programmes, is not the only potential source of rural employment growth, but one amongst many other branches". Zur Rolle des Tourismus als Hoffnungsträger verwiesen McAreavey und McDonagh (2010, S. 13) darauf, dass es paradox sei "to replace one vulnerable activity (agriculture) with another (tourism)".

Eine generelle Frage ist, wer in der Region (Pike et al., 2007) vom Tourismus profitiert. So kann die Gründung eines touristischen Betriebes ein ausreichend hohes Zusatzeinkommen bedeuten und sich auch gut in die Lebensplanung der Familien dieses Tourismusbetriebes einpassen. Dies ist aber keine Option für ökonomisch besonders schlecht gestellte Akteure, da diese in der Regel keinen Zugang zu Kapital für die Gründung eines solchen Betriebes haben (Iorio und Corsale, 2010). Allgemein ist auch die oftmals geringe Qualität touristischer Arbeitsplätze zu berücksichtigen (z. B. schlechte Bezahlung, Saisonarbeit (vgl. Deller, 2010)).

Diese Erkenntnisse relativieren die Möglichkeiten des Tourismus als Faktor der Regionalentwicklung besonders im Hinblick auf periphere ländliche Räume ohne entsprechend inwertsetzbare touristische Alleinstellungsmerkmale deutlich (und diese Relativierung ist auch für die Modellregionen voll zutreffend).

Zudem beeinflusst der Tourismus auch soziale, kulturelle und ökologische Aspekte, wobei jeweils positive aber auch negative Wirkungen möglich sind (Pollermann, 2004; Cawley und Gillmor, 2008; McAreavey und McDonagh, 2010). Es ist aber auch daran zu erinnern, dass für die ökonomische Entwicklung einer Region nicht nur primär ökonomische Faktoren relevant sind. So spielen diesbezüglich auch soziale Beziehungen und Netzwerke ein wichtige Rolle (Agarwal et al., 2009). Somit ist für eine Bewertung der Potenziale des Tourismus auch zu betrachten wie touristische Aktivitäten und Planungen auf die regionale Vernetzung und die Kooperationsbereitschaft von unterschiedlichen Akteursgruppen wirken (auch als Form von „Destination Governance" im Sinne eines kooperativen Netzwerkes zur Entwicklung einer touristischen Destination, vgl. Pollermann, 2011). Hier sind auch Wechselwirkungen zwischen Kooperationen und raumbezogenen Identitäten zu beachten: "cooperation facilates the creation and maintenance of networks and public/private partnerships and may result in local synergy […] In addition, a cultural-territorial identity may also serve as a main catalyst in raising local consciousness towards cooperation" (Terluin, 2003, S. 342).

3 Charakterisierung des Modellprojektes und Einordnung in die Förderpolitik

Ziel des Modellprojektes war es aufzuzeigen, wie in den neuen Bundesländern über die Entwicklung eines Dorftourismus „zusätzliche Einkommensquellen für die Landwirtschaft und die ländliche Bevölkerung in peripheren ländlichen Gebieten der neuen Bundesländer erschlossen werden können, um auf diese Weise einen Beitrag zur Stabilisierung ländlicher Räume in den neuen Bundesländern zu leisten" (Fink und Plankl, 1998, S. 3ff).

Des Weiteren sollten die Motivation der Bevölkerung vor Ort zum eigenverantwortlichen Engagement und ihre Befähigung zum Aufbau und Erhalt langfristig stabiler Existenzen gefördert werden. Angestrebtes Ergebnis waren Angebote zu „Urlaub auf dem Lande" mit entsprechenden Freizeitangeboten im Sinne eines „sanften Tourismus" (vgl. Schilling, 1997). Die Entwicklung des Tourismus sollte durch eine sinnvolle Verknüpfung von bestehenden Fördermöglichkeiten die Zusammenarbeit regionaler kommunaler und privater Dienstleistungsanbieter unterstützt werden sowie die Aktivierung und Koordinierung von Maßnahmen bestehender Institutionen zur Förderung des Landtourismus erreichen (vgl. Fink und Plankl, 1998, S. 3ff).

Da es ein Anliegen des Projektes war, dass dessen Erkenntnisse einen möglichst hohen Allgemeingültigkeitscharakter haben, sollten Möglichkeiten und Grenzen der Entwicklung des ländlichen Tourismus in „Allerweltsdörfern" aufgezeigt werden (vgl. Fink und Plankl, 1998). Bei der Auswahl der Modellregionen wurde daher darauf geachtet, Gemeinden mit unterschiedlicher, aber nicht besonders herausragender touristischer Eignung auszuwählen, die nicht über einen bereits stärker entwickelten Tourismus verfügten (vgl. Schilling, 1997). Dadurch sollte gewährleistet werden, dass der Ausbau des Tourismus ohne Beeinflussung durch bereits vorliegende Erfahrungen und Strukturen erfolgen kann (vgl. Fink und Plankl, 1998). Für jedes der neuen Bundesländer wurde eine für das Bundesland typische Region in das Modellvorhaben einbezogen (vgl. Fink und Plankl, 1998). Typisch ist dabei in dem Sinne zu verstehen, dass eine Projektregion ausgewählt wurde, die keine besonderen Alleinstellungsmerkmale innerhalb des Bundeslandes aufweist und von der Struktur beispielhaft für einen Großteil der Gemeinden, Ämter oder Verwaltungsgemeinschaften innerhalb des Bundeslandes ist. Als Modellregionen wurden relativ kleine Gebiete abgegrenzt. Somit bezieht sich das Modellprojekt eher auf die *lokale*

Ebene (dennoch wird hier vereinfachend der Begriff Modell*region* verwendet, auch wenn der Regionsbegriff eigentlich größere Gebiete erwarten lassen würde).
Durchgeführt wurde das Modellvorhaben in den fünf ostdeutschen Kommunen Gemeinde Glaisin (Mecklenburg-Vorpommern), Amt Schlieben (Brandenburg), Verwaltungsgemeinschaft Kläden (Sachsen-Anhalt), Gemeinde Brunnhartshausen (Thüringen) und Verwaltungsgemeinschaft Lawalde (Sachsen). Die Einwohnerzahl der Projektgebiete variiert dabei zwischen 357 und 9877 Einwohner (Einwohnerstand 2007). Die Lage der fünf Regionen ist in Abbildung 1 dargestellt.

Abbildung 1:
Übersicht über die Lage der Modellregionen

Hinsichtlich einer weiteren Charakterisierung der fünf Modellregionen ist festzuhalten, dass diese alle als periphere ländliche Räume mit geringen Bevölkerungsdichten zu charakterisieren sind, sie liegen nicht in näheren Einzuggebieten von Agglomerationen. Einen Überblick über die touristische und landschaftliche Attraktivität der Regionen kann aus dem Raumordnungsbericht 2005 des Bundesamtes für Bauwesen und Raumordnung entnommen werden: Die Modelldörfer befinden sich dabei in Regionen mit folgenden Indexwerten (fünfklassiger Index, I. < 70, II. 70 <= 100, III. 100 <= 130, IV. 130 <= 160, V. > 160, wobei ein höherer Wert eine höhere Attraktivität darstellt): Glaisin, Kläden in der untersten Klasse I; Lawalde, Schlieben in Klasse II und Brunnhartshausen in Klasse III.

Das Modellprojekt als Teil einer Förderpolitik für den ländlichen Raum lässt sich als „gebietsbezogener" und „partizipativer" Förderansatz charakterisieren. Somit entspricht er prinzipiell aktuellen Forderungen (vgl. Mose und Nischwitz, 2009; BAG LAG, 2010) und ähnelt Förderansätzen wie dem europäischen LEADER, dem bundesweiten Wettbewerb Regionen aktiv oder Plenum in Baden-Würtemberg.[6] Als Unterschiede sind die Eingrenzung auf einen touristischen Fokus sowie die vergleichsweise kleinen Planungsräume zu nennen. Durch den Verzicht auf ein eigenes Budget für die Region, bei Förderung der Beratung ähnelt es in dieser Hinsicht dem Wettbewerb Regionen der Zukunft (vgl. Bräuer et al. 2000) oder den über die EU geförderten ILE (Integrierte ländliche Entwicklung)-Regionen.[7]

Dabei sind externe Anreize oft ein wesentlicher Anstoß, dass überhaupt akteursorientierte Prozesse entstehen (vgl. Fürst et al., 2006). Die Anwendung eines partizipativen Förderansatzes bei einem thematischen Fokus auf einer touristischen Entwicklung entspricht dabei den Anforderungen eines *integrierten* Tourismus „For an integrated rural tourism […] the empowerment of local people should be part of the objective" (Cawley and Gillmore, 2008). Allerdings ist die Fokussierung des Modellprojektes auf den Tourismus vor dem Hintergrund der in Kapitel 2.2. genannten Restriktionen kritisch zu hinterfragen, ein Idealbild einer Förderung via Tourismus wäre: "A sustainable approach to tourism avoids an unbalanced approach to economic growth by using tourism as a tool for broader economic progress, actively seeking alternatives to tourism" (Lane, 1994, S. 19).

4 Vorgehen der Nachuntersuchung

In der hier im Fokus stehenden Nachuntersuchung von 2005 bis 2009 wurden die langfristigen Wirkungen[8] des

[6] Zur aktuellen Bewertung von LEADER Peter und Pollermann, 2010; Fengler und Pollermann, 2010 oder McAreavey und McDonagh, 2010; von Plenum in Baden-Würtenberg vgl. Schramek et al., 2010; von Reginen aktiv: Krott et al., 2007 oder Elbe, 2007.

[7] Beispielsweise in Niedersachsen (Fengler und Raue, 2010) oder in Hessen (Moser und Schnaut, 2010).

[8] Zu erwähnen ist, dass diese Nachuntersuchung bedauerlicherweise nicht bereits zu Beginn des Modellprojektes mitkonzipiert wurden, so hätte ein Forschungsdesign aus einem Guss (mit Hypothesen und Monitoringkonzept) sicherlich die Erfassung von Datengrundlagen und Bewertungen erleichtern können. So wurden seinerzeit keine Indikatoren und messbare Zielgrößen vorgegeben, so dass sich hieraus eine Schwierigkeit für die Ableitung von Erfolgskriterien ergab. Es wurden schwerpunktmäßig qualitative Verfahren der empirischen Sozialforschung eingesetzt. Der eingeschlagene Weg der Erkenntnisgewinnung ist derjenige der Induktion.

Modellprojektes über folgende vier methodische Zugänge analysiert:

1. In einer **Ortsbegehung und Expertengesprächen** wurde der Ist-Zustand mit den im Bericht zur Begleitforschung registrierten Ergebnissen (vgl. Fink und Plankl, 1998) verglichen, um die sich seit dem Modellvorhaben vollzogene Entwicklung zu erfassen. Dazu wurden ca. 12 Schlüsselpersonen wie Bürgermeister und Amtsvorsteher mittels leitfadengestützter Interviews befragt. Zusätzlich wurden Eindrücke, die die Modellgebiete beim Besuch vermittelten, festgehalten.
2. Mittels einer **Bürgerbefragung** und dem Vergleich der Ergebnisse mit einer im Anschluss an das damalige Modellvorhaben 1996 stattgefundenen Befragung wurde ermittelt, wie die Bürger der Modellregionen die Entwicklung in den Zielbereichen des Modellvorhabens aus heutiger Sicht einschätzen und welche Rolle aus ihrer Sicht das Modellvorhaben für diese Entwicklung hatte. Befragt wurden 1996 und 2007 pro Modellregion jeweils etwa 60 Bürger mittels persönlicher Interviews mit einem standardisierten Fragebogen. Die Auswahl der Befragten erfolgte jeweils mittels einer geschichteten Bevölkerungsstichprobe mit Auswahl nach Zufallsprinzip.
3. Im Rahmen eines zweitägigen **Expertenworkshops** mit 16 Akteuren aus den fünf Projektgebieten (aus der Verwaltung, ehemalige Projektmitarbeiter, Tourismusakteure) wurde das Modellvorhaben aus Sicht der Experten in der Retrospektive diskutiert und bewertet.
4. In zwei Projektgebieten (Glaisin, Kläden) wurden exemplarisch **Fallstudien** auf Grundlage narrativer Interviews mit damals Beteiligten sowie mit aktuell in der Regionalentwicklung der Projektgebiete aktiven Personen geführt (15 Interviews pro Ort). Ziel der Fallstudien war es, die gewonnenen Erkenntnisse zu verfeinern sowie Faktoren, die für den Erfolg des Modellvorhabens maßgebend waren, zu untersuchen.

Um Erkenntnisse aus diesen empirischen Erhebungen zumindest in gewissem Maße verallgemeinern zu können, erfolgte zudem eine Auswertung von Literatur zu Regionalentwicklung/Tourismus sowie diesbezüglicher Einfluss- und Erfolgsfaktoren.

5 Entwicklung in den Modellregionen

Insgesamt haben die Begleitforschung und die Nachuntersuchung folgendes Bild ergeben: Durch das Modellvorhaben wurde zwar ein Grundstock für eine weitere touristische Entwicklung gelegt, jedoch mit begrenzten Ausbaumöglichkeiten und begrenzter Reichweite. Es konnten eine Vernetzung der touristischen Aktivitäten in den Regionen sowie die Entwicklung von touristischen Marketingmaßnahmen erreicht werden, teilweise regionale touristische Verbandsstrukturen geschaffen und eine positive Einstellung der Bürger vor Ort zum Tourismus erreicht werden.

Des Weiteren ist es u. a. gelungen, ein Kultur- und Freizeitangebot auszubauen. Beispiele sind Backhäuser, Naturlehrpfade, Heimatmuseen, regionale Märkte und Kulturscheunen. Diese werden überwiegend auch heute noch intensiv genutzt. So ermöglicht die geschaffene Infrastruktur, kulturelle Angebote (Konzerte, Dichterlesungen, Theaterveranstaltungen, Ausstellungen) für die Bevölkerung anzubieten. Insgesamt scheint diese Infrastruktur in den Regionen auch einen bedeutenden Beitrag zur Stärkung der raumbezogenen Identität zu leisten. Allerdings zeigt eine genauere Betrachtung auch, dass die geschaffene Infrastruktur hauptsächlich von Tagestouristen sowie Bürgern der Region und deren näherem Einzugsbereich genutzt wird. Die infolge des Modellvorhabens geschaffene touristische Infrastruktur dient also hauptsächlich dem Naherholungs- und Tagestourismus und hat somit nur eine begrenzte weiter reichende touristische Bedeutung. Hinzu kommt, dass die touristische Infrastruktur z. T. über die Einwerbung von Fördermittel, wie z. B. LEADER, finanziert wurden, ohne dass ein entsprechend tragfähiges Betriebskonzept für die Zeit nach dem Auslaufen der Förderung existiert und hier z. T. Unsicherheiten über die Zukunft der Einrichtungen bestehen.

Inwieweit die touristische Entwicklung nach Einschätzungen der befragten Bürger in den verschiedenen Modellregionen[9] langfristig positive Wirkungen entfaltet hat, illustrieren die in Tabelle 1 zusammengefassten Ergebnisse der Bürgerbefragung. Dargestellt sind unter Hinzuziehung der Daten der Befragung von 1996 die Auswirkungen des Tourismus in den Modellregionen aus Sicht der befragten Bürger als arithmetische Mittel. Dazu wird über die Pfeile ein Vergleich zwischen den Werten von 1996 und 2007 visualisiert.

Am positivsten wurde die Wirkung insgesamt in den Bereichen Dorfbild und Erschließung von Rad- und Wanderwegen eingeschätzt (wobei die Bewertungen auf zwar positivem Niveau kaum noch Weiterentwicklungen zwischen der Befragung 1996 und 2007 aufwiesen) sowie bereits etwas geringer der Bereich Umsatzsteigerungen in Gastronomie und Einzelhandel.

Die Hoffnung, die touristische Entwicklung könne eine positive Wirkung auf den Erhalt von öffentlichen Einrichtungen ermöglichen und zu einer guten Verkehrsan-

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[9] Dabei bestehen zwischen den fünf Modellregionen einige Unterschiede. Diese werden in der Nachuntersuchung (vgl. Neumeier et. al., 2011) auch ausführlicher diskutiert, an dieser Stelle sei lediglich darauf verwiesen, dass wichtige Gründe für positive Entwicklungen in dem kontinuierlichen Engagement von einigen Schlüsselpersonen zu sehen sind. Tendenziell positiv war auch eine aktivierende Form der Bürgerbeteiligung.

Tabelle 1:
Übersicht über die Lage der Modellregionen

	Brunnhartshausen			Glaisin			Kläden			Lawalde			Schlieben			Gesamt		
	96	07	vgl.	96	07	vgl.	96	07	vgl.	96	07	vgl.	96	07	vgl.	96	07	vgl.
Durch den T. sind die Einkommens- und Erwerbsmöglichkeiten verbessert.	3,3	4,5	↘↘	3,2	3,0	→	3,3	3,5	→	3,1	3,1	→	3,7	3,9	→	3,3	3,6	→
Der T. führt zu Umsatzsteigerungen in Gastronomie und Einzelhandel.	2,6	3,7	↘↘	3,0	1,9	↗↗	2,7	3,2	↘	2,4	2,7	→	2,6	3,6	↘↘	2,7	3,0	→
Der Ausbau des T. führt zu einer besseren Auftragslage der Hand¬werksbetriebe.	3,8	4,0	→	3,5	3,2	→	3,3	3,8	↘	2,8	3,7	↘↘	3,9	4,4	↘	3,5	3,8	→
Der T. trägt zu einer guten Verkehrsanbindung bei.	4,0	4,1	→	3,3	2,3	↗↗	3,4	3,8	→	3,4	3,6	→	4,1	4,4	→	3,6	3,6	→
Der T. trägt zur Erhaltung von öffentlichen Einrichtungen in der Region bei.	4,5	4,9	→	3,5	3,7	→	3,9	4,0	→	3,4	3,6	→	3,9	4,2	→	3,8	4,1	→
Der T. ermöglicht die Erschließung von Rad- und Wanderwegen.	2,7	3,1	→	2,2	1,9	→	2,0	2,7	↘	2,3	3,1	↘↘	2,7	2,7	→	2,4	2,7	→
Angeregt durch den T. wurde das Dorfbild attraktiver gestaltet.	2,9	2,8	→	1,9	1,8	→	2,4	3,1	↘	1,8	2,4	↘↘	2,9	3,2	→	2,4	2,7	→
Gesamt / Arithmetische Mittel	**3,4**	**3,9**	↘	**2,9**	**2,5**	→	**3,0**	**3,4**	→	**2,7**	**3,2**	↘	**3,4**	**3,8**	→	**3,0**	**3,4**	→

96 = Befragung von 1996; 07 = aktuelle Befragung von 2007.
1 = „trifft voll und ganz zu“; 5 = „trifft überhaupt nicht zu“
Mittelwertsunterschied zwischen den Wirkungseinschätzungen von 2007 und 1996:
↗↗ = d ≥ 0,80; ↗ = d ≥ 0,50; → = |d| < 0,50; ↘ = d ≤ -0,50; ↘↘ = d ≤ -0,80.

[a] Die Auswertung erfolgte anhand der Häufigkeitsauszählungen der gegeben Antworten. In der Darstellung erfolgt aus Platz- und Übersichtlichkeitsgründen eine Komprimierung als Mittelwerte.

Quelle: Neumeier et al., 2011

bindung beitragen, wird mehrheitlich als nicht erfüllt angesehen. Dies gilt auch für Wirkungen auf die Handwerksbetriebe, sodass nach Wahrnehmung der Bewohner die ökonomische Wirkung, wie sie für eine wirkliche Stützung der regionalen Entwicklung notwendig wäre, als eher weniger gegeben angesehen wird.

Hinsichtlich des Vergleiches der Befragungen von 1996 und 2007 ist außerdem festzuhalten, dass die Bewertungen 2007 in den meisten Bereichen eher etwas schlechter ausfielen als 1996. Daraus lässt sich folgern, dass in den zehn Jahren nach Abschluss des Modellprojektes im Hinblick auf die touristische Entwicklung keine positive Eigendynamik stattfand, auch wenn die meisten Wirkungen als relativ stabil angesehen werden können. Dies bestätigen auch die Ergebnisse des 2008 durchgeführten Workshops sowie der Fallstudien.

Eine maßgebliche Einkommenssicherung für die Bevölkerung auf Basis des Tourismus konnte aber in keiner der Modellregionen erreicht werden. Tourismus wird im Nebenerwerb betrieben und trägt dabei allenfalls zu einer Einkommensergänzung insbesondere aufseiten der wenigen Zimmeranbieter[10] bei. Allerdings ist es möglich, durch den Tourismus z. B. in der Gastronomie, den Tourismusbüros oder den touristischen Einrichtungen Arbeitsplätze auf Basis geringfügiger Beschäftigung/ABM-Maßnahmen/1-Euro-Jobs anzubieten. Zu beurteilen ist dies jedoch ambivalent: Die psychologische Bedeutung der Teilhabe am Erwerbsleben ist für die betroffenen Bürger oft positiv. Allerdings bieten solche Beschäftigungsmöglichkeiten keine längerfristige Perspektive und Kontinuität. Es ließen sich in den Fallstudienregionen keine weiteren auf das Modellvorhaben zurückzuführenden wirtschaftlichen Impulse außerhalb des ländlichen Tourismus feststellen.

Zusammenfassend lässt sich aus den Erkenntnissen der Nachuntersuchung festhalten, dass das Modellprojekt in den Projektgebieten zwar langfristig wirksame Entwicklungsimpulse im Bereich der Dorfentwicklung, Stärkung der raumbezogenen Identität und Forcierung der Zusammenarbeit der Akteure ausgelöst hat, gleichzeitig

[10] Eine Bewertung der Entwicklung über Übernachtungszahlen ist nicht möglich, da die Pensionen in den Modellregionen zu klein sind, um in der Fremdenverkehrstatistik erfasst zu werden.

sich jedoch die mit der Entwicklung des Dorftourismus verbundenen eigentlichen Erwartungen an eine Einkommenssicherung und Etablierung eines tragfähigen ländlichen Tourismus nicht erfüllt haben.

6 Möglichkeiten und Grenzen der Förderung durch touristische Entwicklung im Modellvorhaben

Wenn man die vorgestellten Ergebnisse zur Entwicklung eines ländlichen Tourismus in den Modellregionen mit den konzeptionellen Zielen des Modellprojekts vergleicht, wird deutlich, dass das Modellprojekt in ökonomischer Hinsicht keine weiter reichenden nachhaltigen Effekte ausgelöst hat, da das Hauptziel der Einkommenssicherung und Stabilisierung der regionalen Wirtschaft über den Tourismus in keiner Modellregion erreicht werden konnte. Zusammen mit den literaturgestützten Überlegungen in Kapitel 2 zeigen sich somit enge Grenzen für ökonomische Wirkungen. Dabei hat auch der breite Beteiligungsansatz kaum einen Einfluss auf die Entwicklung touristischer Unternehmen genommen, auch wenn das Thema Tourismus eine breite Diskussion erfahren hat, was vor dem Hintergrund der Vielschichtigkeit von Anforderungen des Tourismus (u. a. positive Einstellung der Bevölkerung) tendenziell positiv zu werten ist.

Im Lauf der Zeit haben sich die Erwartungen aufseiten der Regionen auch relativiert. Die Chancen der touristischen Möglichkeiten werden in den Modellregionen heute durchweg realistischer eingeschätzt, was sich letztlich zunächst als Ernüchterung zeigte, nun aber auch eine pragmatische Herangehensweise fördern kann.

Bezüglich anderer Möglichkeiten ist das Modellvorhaben als erfolgreicher zu beurteilen: so wurden in allen Modellregionen Bürgerbeteiligungsprozesse angestoßen und zur Stärkung der Identifizierung der Bürger mit der eigenen Region beigetragen. Hierzu zeigen die Erörterungen in Kapitel 2 das dieses kein Selbstzweck ist, sondern verbesserte Kooperationsbedingungen sowie gesteigerte Identitäten weitere positive Wirkungen haben können. So hat das Modellvorhaben für die weitere Entwicklung bedeutsame soziokulturelle und soziopolitische Effekte ausgelöst. Die soziokulturellen Effekte entstehen durch eine verbesserte soziale Infrastruktur, die Kommunikation sowie verbesserten Kultur- und Erholungsangebote ermöglicht. Als soziopolitische Aspekte sind die Aktivierung der Betroffenen und ein verändertes Verständnis von Partizipation zu nennen. Allerdings ist die Zustimmung zu partizipativen Verfahren zwar positiv zu bewerten, eine solche Zustimmung hat aber nur dann einen nachhaltigen Effekt, wenn weitere partizipative Beteiligungsansätze zur Anwendung kommen.

Das Modellvorhaben nur anhand der ökonomischen Wirkungen zu beurteilen ist jedenfalls zu kurz gegriffen. Auch wenn in solchen Regionen in ökonomischer Hinsicht über den Tourismus nur wenig zu erreichen ist, so hat die Nachuntersuchung auch gezeigt, dass sich dort vielversprechende Möglichkeiten bieten, über das „Vehikel" Tourismus eine Förderung der Regionalentwicklung zu erreichen und die Regionen für ihre Bewohner attraktiver zu machen. Prinzipiell sind auch andere Vehikel als nur Tourismus möglich, Tourismus eignet sich jedoch besonders für eine Suche nach regionalen Potenzialen und einer Verbesserung der raumbezogenen Identität, da sich gezeigt hat, dass die Beteiligungsbereitschaft und Interesse an Diskussionen über Tourismus i. d. R. groß ist. Wenn es also gelingt, über Diskurse zum Tourismus Bürgerbeteiligungsprozesse zu initiieren und zum Nachdenken über alternative, regionsspezifische Entwicklungsmöglichkeiten anzuregen, dann kann der Tourismus auch in solchen Regionen als ein Faktor der ländlichen Entwicklung dienen. Dabei kommt ihm eine Rolle als Auslöser für Entwicklungsimpulse und -bemühungen zu.

Gleichzeitig bestätigen die Erkenntnisse aus dem Modellvorhaben die These Lanes (1994) vom ländlichen Tourismus als Kontinuum und geben einen Hinweis darauf, dass Naherholung, die gemäß der allgemeinen Tourismusdefinition (vgl. Kapitel 2.1) nicht zum Tourismus gezählt wird, im Rahmen des ländlichen Tourismus in die Definition mit einzuschließen ist. Denn wie am Beispiel der Modellregionen gezeigt, kann ländlicher Tourismus eben auch hauptsächlich Naherholungstourismus sein.

Somit sind die Grenzen, aber auch Möglichkeiten des Tourismus als Faktor der Regionalentwicklung deutlich und es stellt sich daher die Frage, wie diese vor Ort optimal genutzt werden können und wie eine Förderung von außen dies unterstützen kann.

7 Chancen nutzen: Ergebnisse des Modellprojekts im Spiegel der Literatur zu regionalen Entwicklungsprozessen

Die Interpretationen der unterschiedlichen Entwicklungen in den verschiedenen Modellregionen sowie eine Literaturrecherche zu Erfolgsfaktoren können zu Erfolgspotenzialen für regionale Entwicklungsprozesse zusammengefasst werden.[11] Werden diese Erfolgspotenziale in den Prozessen vor Ort genutzt und langfristig aus-

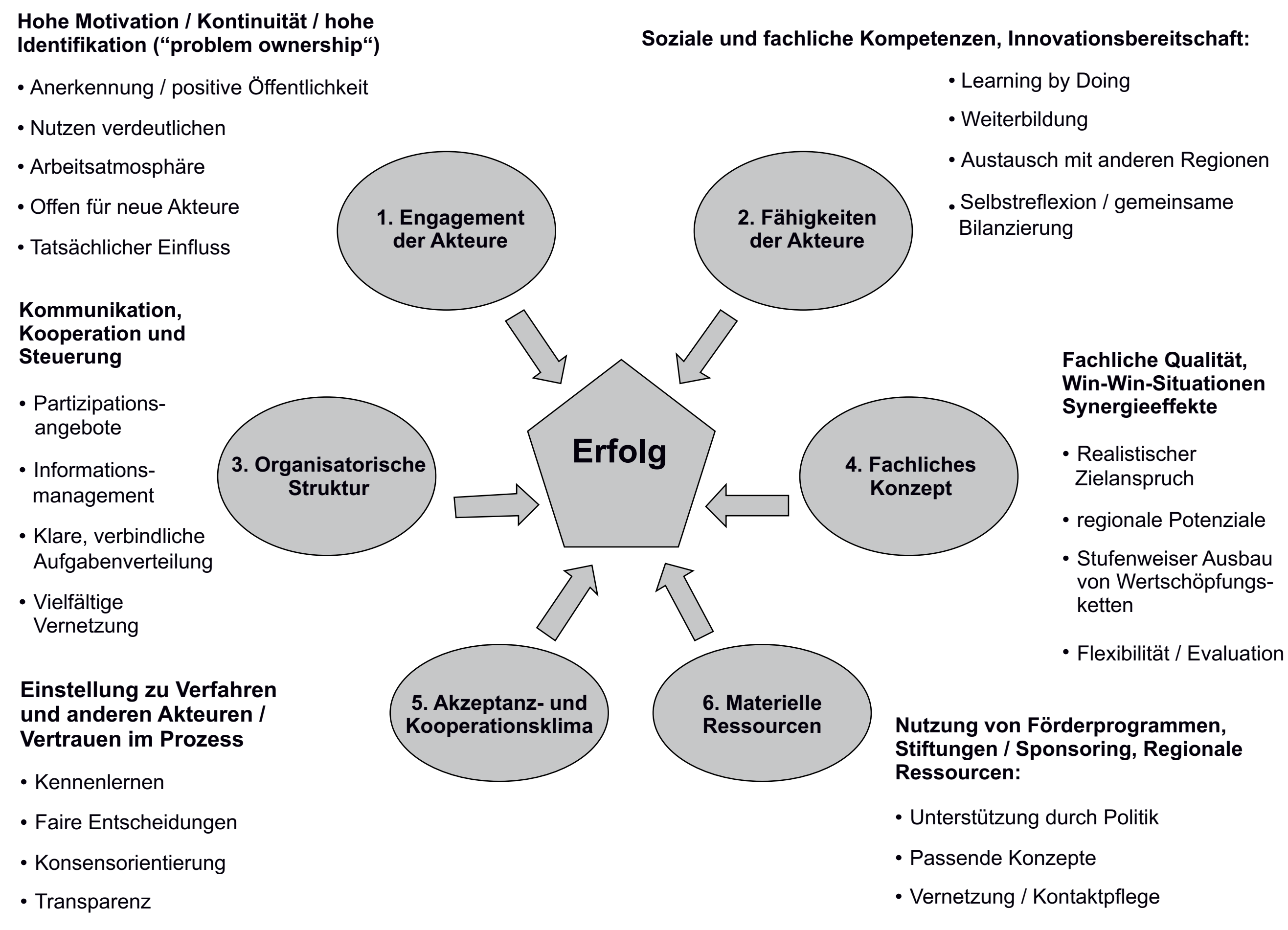
[11] Eine ausführliche Begründungen zur Herleitung der Erfolgspotenziale (und zum Erfolgsbegriff) findet sich bei Pollermann (2004), eine vollständige Liste von Erfolgsfaktoren aus einer Literaturauswertung von 13 Quellen bei Neumeier et al. (2011). Bezug waren verschiedene kooperative Planungsansätze zu integrierter ländlicher Entwicklung (LEADER, Regionen aktiv) und touristische Entwicklungskonzepte. Trotz unterschiedlicher Herkünfte der Literatur und empirischen Grundlagen sind die Erfolgspotenziale relativ universell und passen somit gut auf die Aufgabenstellung, eine touristische Entwicklung in peripheren Regionen zu fördern.

gebaut ist eine erfolgreiche Entwicklung (im Sinne eines Ausschöpfens der jeweils in einer Region realisierbaren Möglichkeiten) wahrscheinlich. Abbildung 2 zeigt sechs als zentral identifizierte Erfolgspotenziale auf und liefert Faktoren, die für eine positive Entwicklung besonders relevant sind (vgl. Neumeier et al., 2011).

Als weiterer für den Umsetzungserfolg entscheidender Faktor sind die spezifischen Rahmenbedingungen zu beachten. Diese Bedingungen beinhalten beispielsweise regionale Gegebenheiten wie den Entwicklungsstand des Tourismus, das generelle touristische Potenzial (vgl. hierzu für Deutschland BBR, 2005, S. 209), Planungserfahrungen oder politische Machtkonstellationen. Die Anforderung des Anpassens an die Rahmenbedingungen lässt sich mit dem Begriff "Strategiefit" beschreiben, welches ein „Passen der Strategie zur Ausgangssituation" beschreibt (vgl. Pollermann, 2004).

Die Erfolgspotenziale von regionalen Prozessen sind dabei durch Modellprojekte oder Förderprogramme beeinflussbar: Beispiele sind Einflüsse auf finanzielle Ressourcen (z. B. in Form von Fördergeldern), organisatorische Strukturen (z. B. durch Initiierung von Arbeitskreisen) oder die Fähigkeiten der Akteure (z. B. durch Beratung/Weiterbildung). Die wesentlichen Ansätze, wie externe Förderungen wirksam werden können, sind in Tabelle 2 zusammengefasst.

Bei der Einschätzung zum Modellprojekt Einkommenssicherung durch Dorftourismus sind einige Spezifika des Modellprojektes zu beachten: (1) Es handelt sich um kleine[12] Räume/Regionen, (2) die Regionen sind struktur-



Quelle: Eigene Darstellung.

Abbildung 2:
Erfolgspotenziale und Erfolgsfaktoren für kooperative regionale Entwicklungsprozesse im Überblick

[12] Als klein wird hier ein Planungsraum klassifiziert, der sich z. B. auf eine einzelne Gemeinde bezieht und/oder Einwohnergrößen von unter 20.000 aufweist.

Tabelle 2:
Ansätze zur Verbesserung der Erfolgspotenziale

Erfolgspotenziale	Externer Einfluss durch Förderprogramme
1. Engagement der Akteure	Unterstützung der Arbeit ehrenamtlich Engagierter durch das Bereitstellen eines Regionalmanagements, das den Rahmen für funktionierende Partizipationsprozesse unterstützt (Einladungen, Protokolle etc.) Motivationsanreize (ideelle Anerkennung, Chancen auf Einfluss oder finanzielle Unterstützung eigener Projekte)
2. Fähigkeiten der Akteure	Lernen im Prozess durch Förderung entsprechender Handlungsarenen Direkte Beeinflussung durch Beratung, Qualifizierungsmaßnahmen Austausch und Vernetzungen mit anderen Regionen
3. Organisatorische Struktur	Finanzierung für Personal Vorgaben an organisatorische Struktur als Fördervoraussetzung
4. Qualität des fachlichen Konzepts	Vorgaben der Gliederung und Mindestinhalte von regionalen Entwicklungsstrategien und der Betriebskonzepte für einzelne Projekte
5. Akzeptanz-/Kooperationsklima	Setzen von Kooperationsanreizen durch finanzielle Mittel (s. bei Engagement) Wenn Zustandekommen von Partizipation unterstützt wird, bietet dies die Chancen für ein Kennenlernen, dass oftmals die Akzeptanz füreinander fördert
6. Materielle Ressourcen	Bereitstellen von finanziellen Mitteln

Quelle: Eigene Darstellung.

schwach, mit einem noch kaum entwickelten Tourismus, (3) es besteht kein herausragendes touristisches Potenzial (also keine Möglichkeiten eines Alleinstellungsmerkmales), (4) es gab eine (Entwicklungs-) Beratung, aber keine eigenen zusätzlichen Fördergelder, (5) es gab einen Hilfe-zur-Selbsthilfe-Ansatz mit eng befristetem zeitlichen Horizont.

Es zeigt sich insgesamt, dass zwar im Ansatz der Planungen einige erfolgsfördernde Aspekte vorhanden waren. So gab es in der Planungsphase des Modellprojekts für alle sechs Erfolgspotenziale durchaus positive Einflüsse. Dennoch sind zwei Hauptprobleme zu konstatieren, die einen wirklichen Erfolg im Sinne der anspruchsvollen Zielsetzung „Einkommenssicherung durch Dorftourismus“ verhindert haben dürften:

- Im Bereich des fachlichen Konzeptes muss durch einen mangelnden Strategie-fit (ungeeignete Räume für einen tragfähigen Tourismus) letztlich eine ungünstige Ausprägung dieses Erfolgspotenzials festgestellt werden, was auch bei günstiger Ausprägung der anderen Erfolgspotenziale den Gesamterfolg limitiert hat.
- Zudem ist festzuhalten, dass in anderen Bereichen die positive Anfangsentwicklung der Erfolgspotenziale als nicht langfristig nachhaltig einzustufen war: Beispielsweise ging das Engagement der Beteiligten zusammen mit dem Wegfall der meisten organisatorischen Strukturen bald wieder zurück. Hier war der Zeithorizont der Selbsthilfeaktivierung zu kurz bemessen bzw. es fehlte an einer stabilisierenden Übergangsphase.

8 Schlussfolgerungen zur Ausgestaltung externer Förderungen

Die Untersuchungen zum Modellprojekt haben gezeigt, dass die sich die Kernelemente des Förderansatzes wie der gebietsbezogene, partizipative Ansatz mit einer Konzentration auf regionsspezifische Entwicklungschance bewährt haben. Dies deckt sich mit Erkenntnissen aus der in Kapitel 3 dargestellten Literatur zu solchen Förderansätzen sowie der ebenfalls dort geschilderten Erkenntnis, dass die Etablierung von kooperativen Netzwerken Impulse für eine wirtschaftliche Entwicklung geben kann.

Um die Stärken akteursorientierter Förderansätze zu nutzen, sollte es ein Fördersystem geben, dass eine gezielte Projektförderung ermöglicht, bei der der zu erwartende Erfolg bezogen auf die individuellen regionalen Bedingungen und Entwicklungsziele das Kriterium für die Bewilligung von Fördergeldern darstellt. Somit wäre die Bindung an strenge Modalitäten und festgeschriebene Gegenstandsbereiche aufgelöst. Dabei kann es durchaus empfehlenswert sein, gerade für kleinere Projekte den gesamten Entscheidungsprozess auf die regionale Ebene zu verlagern: Statt einer Überprüfung „von oben“ würde die Sicherstellung der Effektivität des Mitteleinsatzes durch die beteiligten Akteure gewährleistet. Dem liegt die idealtypische Überlegung zugrunde, dass bei einem begrenzten Globalzuschuss, über den die regionalen Akteure weitgehend frei verfügen können, ein Wettbewerb der guten Ideen entstehen kann (als weitere Praxiserfahrung ist hier auf die gegenwärtige LEADER-Förderung zu verweisen: es gilt eigentlich ein „bottom up"-Prinzip, durch zu enge Fördermodalitäten wird dies aber geschwächt, vgl. BAG-LAG 2010).

Allerdings sind nach unten abgegeben Entscheidungsprozesse in gewissen Maße anfällig gegenüber der Einflussnahme von lokalen Machtkonstellationen, sodass die Sinnhaftigkeit solcher Versuche auch von der Breite und Transparenz der Beteiligungsprozesse abhängt, da so die Gefahr von wenig innovativen, als „Beutegemeinschaften" agierenden Akteurskonstellationen vermindert wird. Somit sollten gerade auch potenziell kritische Akteure aus der Zivilgesellschaft eingebunden und für alle offene Beteiligungsangebote etabliert werden. Zur Erhöhung der Transparenz bieten sich weiterhin an, u. a. im Internet die Einladungen und Protokolle zugänglich zu machen.

Die Untersuchungen zum Modellprojekt bestätigten auch die folgenden Probleme, die durch entsprechende Ausgestaltung der Förderpolitik abgemildert werden können:

- Bei externen Förderungen ist immer zu hinterfragen, inwieweit dauerhaft eigenständige Prozesse entstehen und/oder inwieweit die externe Förderung wirklich einer effektiven Zielerreichung dient. Projekte und Maßnahmen sollten auch nach Auslaufen einer wie auch immer gearteten Unterstützung (fachlich, personell, finanziell) ohne große Probleme oder Einschnitte tragfähig bleiben. Um mit regionalen Entwicklungsmaßnahmen einen nachhaltigen Entwicklungsprozess anzustoßen ist es notwendig, vor Umsetzung von Konzepten und Maßnahmen diese auf ihr Potenzial, auch langfristig tragfähig zu sein, zu prüfen und im Zweifelsfall das Konzept zu modifizieren oder ad acta zu legen. Daher sollte die Vorlage eines fundierten Konzeptes, das insbesondere auch die Fortführung im Anschluss an die eigentliche Projektförderung abdeckt, für entsprechende Maßnahmen und Projekte eine grundlegende Voraussetzung sein.
- Obwohl im Rahmen des Modellvorhabens keine eigenen Fördermittel bereitgestellt wurden, sondern die Modellregionen und Akteure vor Ort „lediglich" über Fördermöglichkeiten informiert/beraten wurden, gibt es Hinweise auf eine Art „Fördermentalität". Das bedeutet, dass Maßnahmen insbesondere nicht nur eher umgesetzt werden, wenn es dafür eine entsprechende Förderung gibt, sondern auch das Fördermittel auch für weniger dringende Projekte beantragt werden, eben weil diese gefördert werden. Zudem können Fehldimensionierungen begünstigt werden. Die Bereitschaft zur Eigeninitiative, d. h. Nutzung vorhandener endogener Möglichkeiten zur Umsetzung von Entwicklungsmaßnahmen, kann zurückgehen. Um dies abzumildern sind wiederum partizipative Ansätze geeignet, können doch auch hier insbesondere kritische Akteure aus der Zivilgesellschaft ein Korrektiv beispielsweise gegenüber Fehldimensionierungen darstellen (vgl. Fengler und Pollermann 2010, S. 87). Gleichzeitig wurde eine Förderberatung wie im Modellvorhaben betrieben von den Workshopteilnehmern sehr begrüßt, da die Fördermöglichkeiten und –modalitäten in der Regionalentwicklung laut Aussage der Workshopteilnehmer inzwischen derart unübersichtlich und bürokratisch sind, dass eine entsprechende Beratung und Hilfestellung sowohl bei der Antragstellung als auch der Abrechnung eine große Hilfe und Entlastung der (Kommunal-)Verwaltungen darstellen würde. Hieraus lassen sich wiederum zweierlei Anforderungen ableiten: einerseits sollten Bestrebungen erfolgen die Förderbedingungen einfacher und transparenter zu machen, anderseits Beratungsangebote über kontinuierlich bestehende Stellen etabliert werden (diese Funktion erfüllen jetzt z.T. die über LEADER eingerichteten Regionalmanagements). Eine transparente Fördermittelberatung kann auch dazu beitragen, dass auch neue Akteure aktiviert werden und sich das Fördermittelgeschäft nicht nur in darauf eingespielten „inneren Zirkeln" abspielt.

9 Fazit

Für den Erfolg von Modellprojekten hinsichtlich ihrer eigentlichen Aufgabe - nämlich modellhafte Erkenntnisse zu liefern - ist dabei die konkrete Zielerreichung vor Ort nur ein Teilaspekt. So ist es zum einen wichtig, dass die über Modellprojekte aktivierten Akteure nach Ende der Vorhaben nicht allein gelassen werden. Zum anderen ist es wesentlich, dass die Wirkungszusammenhänge – gerade auch bei geringen Zielerreichungen – festgestellt werden und daraus Konsequenzen für die Planungspraxis und die Förderpolitik abgeleitet werden. Generell sollte eine entsprechende Vor- und Nachbereitung von Modellprojekten sowohl die Wissens*generierung* optimieren als auch den Wissens*transfer* in die Praxis sicherstellen.

Die Nachuntersuchung zum Modellvorhaben hat gezeigt, dass die „Förderung von Tourismus als Faktor der Entwicklung ländlicher Räume" differenziert zu sehen ist, wobei im Rahmen des Artikels keine touristischen Gunstregionen betrachtet wurden. In solchen bestehen, auch in peripheren Regionen, sicherlich ganz andere Möglichkeiten. Für periphere Regionen ohne besondere touristische Qualitäten („Allerweltsregionen") ist aber nach Erkenntnissen aus dem Modellprojekt eher davor zu warnen, größere ökonomische Hoffnungen auf eine touristische Entwicklung zu setzen. Angesichts der Herausforderungen des demographischen Wandels sowie des sozialen und ökonomischen Strukturwandels sind die Möglichkeiten zu einer ökonomischen Stabilisierung solcher Regionen über den Tourismus begrenzt. Das Modellvorhaben hat aber auch gezeigt, dass mithilfe des Vehikels „Tourismus" vielversprechende Möglichkeiten und Anknüpfungspunkte geschaffen werden können, die regionale Entwicklung zu unterstützen sowie die Attraktivität von Regionen für ihre Bürger und potenzielle Gäste zu erhöhen. Einer der Gründe dafür ist, dass der Aspekt „Tourismus" vor Ort i. d. R. auf großes Interesse stößt, was sich in der Bereitschaft der Bürger und Gemeindevertreter, sich in entsprechende Diskussionen und Projekte einzubringen, widerspiegelt.

Falls es gelingt, über den Faktor Tourismus ländliche Entwicklungsprozesse anzustoßen, Entwicklungsbestrebungen stringent aufeinander abzustimmen oder die Reflexion über unterschiedliche Entwicklungsperspektiven anzuregen, kann Tourismus auch in Regionen, die sich nicht für eine ökonomisch nachhaltige touristische Inwertsetzung eignen, einen wirksamen Beitrag zur ländlichen Entwicklung leisten – und zwar als Initiator für sozio-politischen Wandel. Vorraussetzung dazu ist ein partizipativer, gebietsbezogener und integrierter Förder- und Planungsansatz. Unterstützt werden kann ein solcher Prozess über die dargestellten Erfolgspotenziale. Dabei ist der Tourismus sicherlich nicht der einzig mögliche Anknüpfungspunkt, sondern es ist auch ein direkter Fokus auf die Lebensqualität der Bevölkerung oder anderer regionsspezifischer Aufgaben sinnvoll. Ein touristischer Fokus bietet aber in vielen Regionen Chancen, zumindest kleine Erfolge im ökonomischen Bereich mit einer allgemeinen ländlichen Entwicklung zu verknüpfen.

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Regionale Verteilung finanzieller Staatshilfen für den Agrarsektor – Sind die Nutznießer die ländlichen Räume?

Reiner Plankl*

Zusammenfassung

Die regionale Verteilung der finanziellen Staatshilfen für den Agrarsektor stellt sich bezüglich der Erfassung der Politikmaßnahmen, der Verfügbarkeit von Zeitreihendaten sowie regional disaggregierten Daten immer noch als sehr lückenhaft dar. Der vorliegende Beitrag soll zu mehr Transparenz beitragen. Dazu wird der Umfang der vier bedeutendsten finanziellen Staatshilfen für den Agrarsektor (1. + 2. Säule der GAP, Agrardieselverbilligung und agrarsoziales Sicherungssystem) zunächst hinsichtlich ihres Mittelvolumens abgeschätzt. Darüber hinaus werden die Mittel in Beziehung zu weiteren raumwirksam bedeutenden Ausgaben gesetzt und es werden die regionalen Unterschiede in der Förderintensität für die finanziellen Staatshilfen des Agrarsektors insgesamt sowie für die Maßnahmen der 2. Säule der GAP beschrieben. Es zeigen sich deutlich höhere Förderungen je Einwohner in den ländlichen im Vergleich zu den nicht ländlichen Räumen mit Unterschieden zwischen alten und neuen Bundesländern. Die Ergebnisse der formalen regionalen Inzidenz deuten auf eine nicht zu unterschätzende gesamtwirtschaftliche Bedeutung der Agrarhilfen für die ländlichen Räume hin. Für eine genaue Abschätzung sind u. a. auch die sektoralen und regionalen Verflechtungen des Agrarsektors zu berücksichtigen.

Schlüsselwörter: Finanzielle Staatshilfen, regionale Verteilungsunterschiede, Förderintensität, Landwirtschaft

Summary

Regional distribution of state financial aids for the agricultural sector – Are the winners the rual areas?

The regional distribution of state financial aid for the agricultural sector remains very incomplete with regard to the documentation of the policy measures, the availability of time series as well as regional disaggregated data. This article intends to increase transparency. For this purpose, the volume of the four most important financial state aids for the agricultural sector (first and second pillar of the CAP; agricultural fuel subsidies and the agricultural social security system) will first be estimated. In addition, these funds will be placed in the context of other spatially relevant state expenses. Regional differences in the total financial support of the agriculture as well as in measures of the second pillar of the CAP are described. Higher financial aids per capita are found in rural as opposed to non-rural areas with differences between the former and new German Federal States. The results of the formal regional incidence seems to indicate that the agricultural aid contributes substantially to the economic wealth in rural areas. To estimate the total increase in economic wealth, among others the sectoral and regional intertwining of the agricultural sector must also be considered.

Keywords: financial assistance, spatial distribution of financial aids, promotion intensity, agricultural

* Johann Heinrich von Thünen-Institut (vTI), Bundesforschungsinstitut für Ländliche Räume, Wald und Fischerei, Institut für Ländliche Räume, Bundesalle 50, 38116 Braunschweig, Email: reiner.plankl@vti.bund.de

1 Problemstellung

Über finanzielle Staatshilfen beeinflusst der Staat auf direktem und indirektem Wege das wirtschaftliche Geschehen in einer Volkswirtschaft und nimmt Einfluss auf sektorale und regionalwirtschaftliche Entwicklungsprozesse. Die Intensität der Intervention ist dabei meist sehr unterschiedlich. Da der Agrarsektor als ein stark von finanziellen Staatshilfen abhängiger Sektor gilt, lastet auf dem Sektor ein besonderer öffentlicher Rechtfertigungsdruck bezüglich der Verwendung der ihm gewährten öffentlichen Hilfen. Bei der in Wissenschaft und Politik geführten kontroversen ordnungspolitischen Diskussion um die Notwendigkeit und Zweckmäßigkeit des Umfangs an finanziellen Staatshilfen sind Ziel- und Wirkungsanalysen, insbesondere regional differenzierte Inzidenzanalysen, sehr hilfreich, erfordern jedoch hohe Ansprüche an die methodische Vorgehensweise und an die empirische Datengrundlage (Färber, 2007).

Das Bild der regionalen Verteilung der finanziellen Staatshilfen für den Agrarsektor ist trotz einiger jüngerer Untersuchungen (Hansen, 2005; Harsche, 2009) noch sehr lückenhaft. Über finanziell bedeutende Bereiche der Agrarpolitik, angefangen bei den Maßnahmen der „Gemeinschaftsaufgabe zur Verbesserung der Agrarstruktur und des Küstenschutzes" (GAK) bis hin zu den verschiedenen Flächen- und Tierprämien, den Bundeszuschüssen über das agrarsoziale Sicherungssystem und die Verwendung der Agrardieselvergünstigungen, ist meist nur die Verwendung der Mittel bis auf die regionale Ebene der Bundesländer bekannt. In jüngsten Untersuchungen zur regionalen Inzidenz von raumwirksamen Maßnahmen werden die Agrarfördermittel meist nur nachrangig und nicht mit der notwendigen regionalen Differenziertheit dargestellt (Färber, 2007; Mäding, 2009) oder das Ausmaß der regionalen Verteilungsunterschiede beschränkt sich auf ausgewählte finanzielle Staatshilfen des Agrarsektors für ein Bundesland als Beispielregion (Harsche, 2009; Färber, 2007). Mit der Offenlegung der unternehmensbezogenen EU-Direktzahlungen der 1. Säule der Gemeinsamen Agrarpolitik (GAP), den Daten aus dem Monitoring und den Bewertungsberichten der 2. Säule-Maßnahmen der GAP wurde für bedeutende Teile der finanziellen Staatshilfen des Agrarsektors inzwischen ein wichtiger Schritt in Richtung mehr Transparenz bezüglich der regionalen Verteilung vollzogen. Damit wird es in Zukunft möglich, die Darstellung und Analyse der raumwirksamen Mittel und deren Bedeutung für die wirtschaftliche Entwicklung um wesentliche Teile der finanziellen Staatshilfen für den Agrarsektor zu vervollständigen.

Der folgende Beitrag nimmt die finanziellen Staatshilfen für den Agrarsektor in den Fokus und will durch eine retrospektive Beschreibung der regionalen Verteilung dieser Mittel für mehr Transparenz sorgen. Um eine Vorstellung vom Umfang und von der relativen Bedeutung der finanziellen Staatshilfen des Agrarsektors zu bekommen, wird zunächst das Ausgabevolumen für Deutschland insgesamt quantifiziert und die relative Bedeutung der finanziellen Staatshilfen des Agrarsektors zu weiteren raumwirksamen Finanzhilfen abgeschätzt. Im Zentrum stehen die vier großen Ausgabenbereiche der Agrarpolitik: die aus dem Europäischen Garantiefonds für Landwirtschaft (EGFL) gewährten Direktzahlungen der 1. Säule der GAP, die aus den Mitteln des Europäischen Landwirtschaftsfonds für die Entwicklung des ländlichen Raumes (ELER) und den Bundes- und Landesmitteln finanzierten Maßnahmen der 2. Säule der GAP, die im Bundeshaushalt verbuchten Ausgaben für Agrardieselverbilligung sowie die Bundeszuschüsse für das agrarsoziale Sicherungssystem. Als Untersuchungszeitraum wurden die Jahre 1995 bis 2008 gewählt.

Die regionalen Verteilungsunterschiede werden für die vier finanziellen Staatshilfen des Agrarsektors insgesamt sowie für die Ausgaben der Maßnahmen zur Entwicklung der ländlichen Räume (2. Säule der GAP) mithilfe von Karten auf der Ebene der Landkreise beschrieben und es werden die Unterschiede zwischen den verschiedenen ländlichen und nicht ländlichen Kreisen im Sinne der siedlungsstrukturellen Kreistypen des Bundesamtes für Bauwesen und Raumordnung (BBR, 2008) in den alten und neuen Bundesländern analysiert. Auf der Ebene der ländlichen und nicht ländlichen Kreise wird zudem die relative Bedeutung der einzelnen finanziellen Staatshilfen des Agrarsektors beschrieben. Da in dem Beitrag nicht die flächen- bzw. betriebsbezogene Agrarförderintensität Untersuchungsgegenstand ist[1], sondern die Agrarförderung hinsichtlich ihrer Bedeutung für die regionale und räumlich wirtschaftliche Entwicklung beschrieben werden soll, werden die finanziellen Staatshilfen auf die Einwohner normiert. Durch die Normierung wird es auch möglich, einen Vergleich mit anderen raumwirksamen Förderbereichen durchzuführen. In einem abschließenden Resümee wird auf einige Aspekte der Bedeutung der Agrarförderung für die ländlichen Räume eingegangen.

2 Finanzielle Staatshilfen für den Agrarsektor

Durch finanzielle Staatshilfen in Form von Subventionen, Steuervergünstigungen und Beiträgen für soziale Leistungen fließen dem Agrarsektor direkte und indirekte Einkommenstransfers zu, durch welche nicht nur die Einkommenslage und soziale Lage der Landwirte, ihrer Familienangehörigen und der im Agrarsektor Beschäftigten

[1] Zur sektoralen Bedeutung der finanziellen Staatshilfen vgl. Plankl (2011).

unmittelbar verbessert werden, sondern vielmehr kann es durch eine vermehrte Konsum- und Investitionsgüternachfrage je nach regionaler bzw. überregionaler Verwendung der Einnahmen zu Ausstrahlungseffekten auf andere Branchen sowie auf die in der Region lebenden Menschen kommen. Die Effekte auf die regionale wirtschaftliche Entwicklung sind dabei sehr vielfältig und hängen u. a. von der regionalen effektiven Inzidenz der einzelnen finanziellen Staatshilfen ab. Die Messung der effektiven regionalen Wirkungen stellt hohe Ansprüche an die Methode und an das Datenmaterial. Die Untersuchung erhebt nicht den Anspruch, die effektiven Wirkungen zu messen, sondern es wird eine ausführliche, regional differenzierte Darstellung der finanziellen Staatshilfen des Agrarsektors vorgenommen.

Der Begriff der finanziellen Staatshilfen des Agrarsektors wird in der Literatur nicht einheitlich definiert.[2] Orientiert man sich bei der Ermittlung an der landwirtschaftlichen Gesamtrechnung (LGR), dann setzen sich die dort als Subventionen bezeichneten finanziellen Staatshilfen aus den Produktsubventionen (Flächenzahlungen und Tierprämien (ab 2005 Betriebsprämien)) und den Sonstigen Subventionen (Ausgleichszulage, Investitionsbeihilfen, Agrarumweltmaßnahmen, Agrardieselerstattung) zusammen. Für 2006 betragen die Subventionen für den engeren Sektor Landwirtschaft (ohne die Bereiche Forst und Fischerei) rd. 6,4 Mrd. Euro (BMELV, 2007a). Der Subventionsbegriff der LGR ist im Vergleich zu anderen Definitionen eher eng abgegrenzt. So werden öffentliche Hilfen für die Landwirtschaft i. S. von staatlichen Ausgaben für die Agrarsozialpolitik, vergleichbar zu den staatlichen Aufwendungen für andere soziale Sicherungssysteme in der allgemeinen volkswirtschaftlichen Gesamtrechnung (VGR), nicht als Subventionen definiert. Dadurch bleiben rund. 3,8 Mrd. Euro unberücksichtigt.

Greift man für die Erfassung der finanziellen Staatshilfen des Agrarsektors auf die Daten des 21. Subventionsberichts der Bundesregierung zurück (BMF, 2008), so errechnet sich für das entsprechende Jahr 2006 ein Gesamtsubventionsvolumen in Höhe von 9,57 Mrd. Euro. Hierin enthalten sind die Finanzhilfen des Bundes, die Steuervergünstigungen des Bundes und der Länder sowie die im Subventionsbericht nachrangig ausgewiesenen Finanzhilfen der Länder und die EU-Marktordnungsausgaben. Im Subventionsbericht werden auch die Fördermaßnahmen der GAK berücksichtigt; allerdings werden jene GAK-Fördermaßnahmen, die der Allgemeinheit zugutekommen wie Dorferneuerung, Küstenschutz und die Hälfte der wasserwirtschaftlichen Maßnahmen, nicht als Finanzhilfen für die Landwirtschaft eingestuft. Da die außerhalb der GAK-Maßnahmen angebotenen Fördermaßnahmen zur Entwicklung des ländlichen Raums (2. Säule-Zahlungen) fehlen, kommt es zu einer leichten Unterschätzung. Andererseits werden im Subventionsbericht die Ausgaben des Bundes für die Landwirtschaftliche Unfallversicherung (LUV) und die Steuervergünstigungen als Subventionen erfasst.

Zu einer anderen Summe an finanziellen Staatshilfen für den Sektor Landwirtschaft, Forsten und Fischerei kommt der alternative Subventionsbericht des Kieler Instituts für Weltwirtschaft (Boss und Rosenschon, 2008). Für 2007 werden dort an gesamten Subventionen für den Agrarsektor 10,74 Mrd. Euro ausgewiesen; 10,12 Mrd. Euro entfallen auf die öffentlichen Finanzhilfen und 0,62 Mrd. Euro auf Steuervergünstigungen. Zu einem vergleichbaren Niveau kommt der Raumordnungsbericht der Bundesregierung. Für die Förderperiode 1999 bis 2003 weist dieser ein jahresdurchschnittliches Mittelvolumen für Maßnahmen der Agrarpolitik in Höhe von 10,55 Mrd. Euro aus; dabei sind die Ausgaben des Bundes für das agrarsoziale Sicherungssystem, nicht jedoch die Steuervergünstigungen, berücksichtigt (BBR, 2005).

Eigenen Berechnungen zufolge liegen die finanziellen Staatshilfen für den Agrarsektor aus EU-, Bundes- und Landesmittel bei Berücksichtigung der Maßnahmen der 2. Säule der GAP (einschließlich Artikel-89-Maßnahmen), den Bundeszuschüssen für das gesamte agrarsoziale Sicherungssystem, den EGFL-Direktzahlungen und den Sonstigen EGFL-Zahlungen der GAP sowie den Ausgaben für Agrardieselverbilligung im Jahresdurchschnitt für den Untersuchungszeitraum 1995 bis 2008 bei 11,7 Mrd. Euro. Die nicht immer stringente Zurechnung von EU-, Bundes- und Landesmitteln sowie die unterschiedliche Berücksichtigung der Maßnahmen der GAK und des agrarsozialen Sicherungssystems sind neben der unterschiedlichen Abgrenzung des Primärsektors die Hauptgründe für die Varianz in den finanziellen Staatshilfen für den Agrarsektor.

Für die regionalwirtschaftliche Entwicklung bemisst sich die Bedeutung der finanziellen Staatshilfen für die Landwirtschaft nicht ausschließlich an ihrer absoluten Höhe, sondern vielmehr auch am relativen Beitrag im Vergleich zu anderen sektoralen und regionalen raumwirksamen Finanzmitteln. Auch hier ist die Abgrenzung und statistische Erfassung der raumwirksamen Finanzmittel von Bedeutung. Bei einem in Deutschland geschätzten jahresdurchschnittlichen Gesamtvolumen an regionalwirtschaftlich bedeutenden finanziellen Staatshilfen in Höhe von rund 87 Mrd. Euro im Untersuchungszeitraum 1995 bis 2008 machen die Mittel des Agrarsektors rund 13,5 % aus (vgl.

[2] Zum Begriff der finanziellen Staatshilfen für den Agrarsektor und der historisch gewachsenen Bedeutung vgl. Hansmeyer (1963).

Tabelle 1)[3]. Abgesehen von den jahresdurchschnittlichen Ausgaben für Teile der Arbeitsmarktpolitik in Höhe von 34,4 Mrd. Euro bleiben die finanziellen Staatshilfen für den Agrarsektor knapp unter dem Niveau der Ausgaben für Stadtentwicklung und Wohnen sowie den Ausgaben für die großräumige Verkehrspolitik, liegen jedoch deutlich höher als die Ausgaben für die Wirtschaftsförderung und den Bereich Forschung und Hochschule. Zur Erfassung der Ausgaben der einzelnen Politikbereiche orientiert sich die Untersuchung an der Definition der raumwirksamen Mittel in den Bundesraumordnungsberichten des BBR (BBR, 2005). Durch eine engere Abgrenzung der Arbeitsmarktpolitik auf die aktiven Maßnahmen, die Berücksichtigung von Sektorhilfen, Eigenheimzulage, Zuschüsse für sozialen Wohnungsbau, Wohngeld und Hilfe zum Lebensunterhalt sowie die weitgehende Berücksichtigung von EU- und Landesmitteln und durch Unterschiede in der Ermittlung des Subventionswertes von Darlehensprogrammen weichen die in der Untersuchung geschätzten Mittel von den in den Raumordnungsberichten ausgewiesenen Mitteln ab.

Von den rund 87 Mrd. Euro an finanziellen Staatshilfen für die raumwirksamen Politikbereiche entfallen rund 58 Mrd. Euro auf die alten Bundesländer. Im Vergleich zum Einwohneranteil von rund 80 % sind dies rund 67 % der geschätzten regionalwirtschaftlich bedeutenden finanziellen Staatshilfen. Auf die neuen Bundesländer entfällt bei einem Einwohneranteil von 20 % rund ein Drittel der finanziellen Staatshilfen (vgl. Tabelle 1).

Bei einer Normierung der finanziellen Staatshilfen für die raumwirksamen Politikbereiche auf die Einwohner (vgl. Tabelle 1) liegt der durchschnittliche Förderbetrag für die Summe aller Politikmaßnahmen in den neuen Bundesländern[4] mit rund 1.670 Euro um etwa das Doppelte über dem Förderbetrag der alten Bundesländer (890 Euro

Tabelle 1:
Finanzielle Staatshilfen in Mio. Euro und in Euro je Einwohner im Jahresdurchschnitt für die einzelnen raumwirksamen Politikbereiche in den alten und neuen Bundesländern (Untersuchungszeitraum 1995 bis 2008)

Regionen	Politikbereiche						
	Agrarpolitik	Forschung/ Hochschule	Wirtschafts-förderung	Städtebau/ Wohnen	Arbeitsmarkt-politik	Verkehrspolitik	insgesamt
				in Mio. €			
Alte Bundesländer	9.164	3.799	4.386	11.224	21.476	7.872	57.922
Neue Bundesländer	2.545	1.330	2.207	4.646	12.968	4.954	28.652
Deutschland	11.709	5.130	6.593	15.874	34.426	12.832	86.563
				in € je Einwohner			
Alte Bundesländer	141	58	67	172	330	121	889
Neue Bundesländer	149	78	129	271	758	289	1.674
Deutschland	142	62	80	193	418	156	1.052
				Verteilung in %			
Alte Bundesländer	16	7	8	19	37	14	100
Neue Bundesländer	9	5	8	16	45	17	100
Deutschland	14	6	8	18	40	15	100

Erläuterung der Politikbereiche: Agrarpolitik = 1. + 2. Säule der GAP, Agrardieselverbilligung, Agrarsozialpolitik; Forschung/Hochschule = wissenschaftliche Forschung und Förderung der Großforschung, Innovationsprogramme; Wirtschaftsförderung = Gemeinschaftsaufgabe Verbesserung der regionalen Wirtschaftsstruktur (GRW), Förderung kleiner und mittelständischer Unternehmen (KMU), Sektorhilfen; Städtebau/Wohnen = Städtebau, Wohnungsbau, Sozialer Wohnungsbau, GRW-Infrastruktur, KfW-Infrastruktur, Gemeindeverkehrsfinanzierungsgesetz, Eigenheimzulage; Arbeitsmarktpolitik = Teile der aktiven Arbeitsmarktpolitik, Wohngeld, Hilfe zum Lebensunterhalt; Verkehrspolitik = großräumige Verkehrspolitik Straße, Schiene und Wasser. Die Ausgaben berücksichtigen soweit die Datengrundlage es ermöglicht EU-, Bundes- und Landesmittel. Darlehensprogramme wurden mit abdiskontierten Subventionsäquivalenten berücksichtigt.

Quelle: Eigene Berechnungen auf der Grundlage von Daten des Bundesamtes für Bauwesen und Raumordnung (regionale Förderdatenbank, Raumordnungsberichte und INKAR), des Bundesamts für Wirtschaft und Ausfuhrkontrolle sowie verschiedener Daten der amtlichen Statistik. Daten für den Bereich Agrarpolitik vgl. Fußnote 5.

[3] Zur Darstellung der Datengrundlage und der methodischen Vorgehensweise der Ermittlung der Fördermittel ist ein Arbeitsbericht in Vorbereitung (Plankl, 2012).

[4] Da die Fördermittel in der jeweils verwendeten Datengrundlage nicht immer nach Berlin Ost und West differenziert vorliegen, wurde in der Untersuchung Berlin den neuen Bundesländern zugeschlagen. Durch die hohe Einwohnerzahl in Berlin kann es dadurch zu Verzerrungen kommen.

je Einwohner). Bei einer Förderintensität von 149 Euro je Einwohner machen die finanziellen Staatshilfen des Agrarsektors in den neuen Bundesländern an den gesamten finanziellen Hilfen nur 9 % aus. Im Westen liegt das Förderniveau mit 141 Euro je Einwohner knapp 10 Euro niedriger, der Anteil an den gesamten finanziellen Staatshilfen liegt jedoch mit 14 % deutlich höher. Auch wenn die finanziellen Staatshilfen für den Agrarsektor nicht explizit zu den engeren ausgleichs- und raumordnungspolitischen Maßnahmen zählen, mit deren Hilfe ein Beitrag zur Herstellung gleichwertiger Lebensverhältnisse erreicht werden soll, erreichen sie im Durchschnitt Deutschlands eine Pro-Kopf-Förderintensität von 142 Euro je Einwohner. In den alten Bundesländern rangieren sie damit auf Platz 3, in den neuen Bundesländern auf Platz 4 unter den raumwirksamen finanziellen Staatshilfen.

Tabelle 2:
Finanzielle Staatshilfen in Euro je Einwohner im Jahresdurchschnitt für die einzelnen raumwirksamen Politikbereiche (ohne Verkehrspolitik)[1] in den ländlichen und nicht ländlichen Kreisen und kreisfreien Städten (Untersuchungszeitraum 1995 bis 2008)

Regionen	Finanzielle Staatshilfen in € je Einwohner					
	Agrarpolitik	Forschung/ Hochschule	Wirtschafts-förderung	Städtebau/ Wohnen	Arbeitsmarkt-politik	insgesamt
Ländliche Kreise (Kreistypen 4+7+8+9)	310	14	81	270	446	1121
Nicht ländliche Kreise	80	80	79	177	401	818
Differenz ländl. zu nicht ländl. Kreisen	230	-66	2	93	45	303

[1] Mit den in der Untersuchung verfügbaren Daten war es nicht möglich, die Ausgaben für die großräumige Verkehrspolitik nach Landkreisen zu regionalisieren und die Ausgaben anschließend für ländliche bzw. nicht ländliche Kreistypen zu ermitteln.
Erläuterung der siedlungsstrukturellen Kreistypen: 4 = Ländliche Kreise in Agglomerationsräumen, 7 = Ländliche Kreise verstädterter Räume, 8 = Ländliche Kreise höherer Dichte, 9 = Ländliche Kreise geringerer Dichte.
Erläuterung der Politikbereiche: siehe Tabelle 1.

Quelle: Eigene Berechnungen auf der Grundlage von Daten des Bundesamtes für Bauwesen und Raumordnung (regionale Förderdatenbank, Raumordnungsberichte und INKAR), des Bundesamts für Wirtschaft und Ausfuhrkontrolle sowie verschiedener Daten der amtlichen Statistik. Daten für den Bereich Agrarpolitik vgl. Fußnote 5.

Ein Vergleich der Pro-Köpf-Förderintensität zwischen ländlichen und nicht ländlichen Kreisen (vgl. Tabelle 2) weist ohne Berücksichtigung der Ausgaben für die großräumige Verkehrspolitik in den ländlichen Kreisen eine um rund 300 Euro je Einwohner höhere Förderung aus als in den nicht ländlichen Kreisen. 230 Euro je Einwohner erklären sich aus den Förderunterschieden der finanziellen Staatshilfen des Agrarbereichs. In keinem der anderen regionalwirtschaftlich bedeutenden Politikbereiche profitieren ländliche Kreise so stark von den finanziellen Staatshilfen. Absolut liegt die Förderintensität für die arbeitsmarktpolitischen Hilfen zwar um knapp 130 Euro je Einwohner höher, durch die in den nicht ländlichen Kreisen vergleichbar hohe Förderintensität von 401 Euro je Einwohner sind jedoch die Unterschiede in der formalen regionalen Inzidenz wesentlich geringer, sodass von der Agrarförderung die ländlichen Regionen absolut als auch im Vergleich zu anderen Politikbereichen am stärksten profitieren. Da ein Großteil der finanziellen Staatshilfen des Agrarsektors über die Fläche verteilt wird und sich die Agrarhilfen im Vergleich zu anderen raumwirksam bedeutenden finanziellen Staatshilfen durch eine hohe zeitliche Stabilität auszeichnen, gleichen sie ballungsfördernde Tendenzen anderer Maßnahmen aus. Zu diskutieren bleibt jedoch die Frage, wie die finanziellen Staatshilfen des Agrarsektors mit den anderen raumwirksamen Maßnahmen besser abgestimmt werden können, um größere Synergieeffekte und mehr Effizienz zu erreichen.

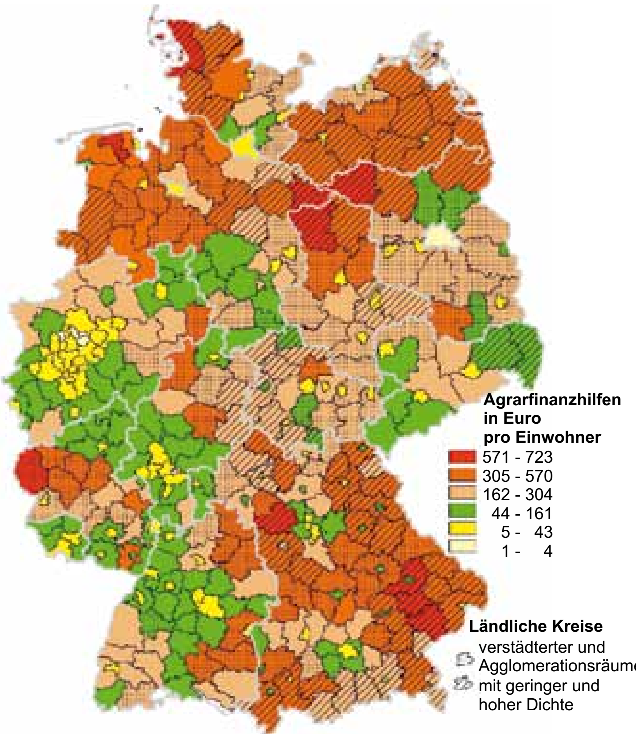
3 Regionale Verteilung der finanziellen Staatshilfen für den Agrarsektor

Die Darstellung der regionalen Verteilung der finanziellen Staatshilfen des Agrarsektors bezieht sich auf die Finanzhilfen der EU, des Bundes und der Länder und umfasst die Ausgaben für die Maßnahmen der 1. Säule bestehend aus den EGFL-Direktzahlungen und den Sonstigen EGFL-Zahlungen, die Ausgaben für die 2. Säule der GAP (einschließlich geschätzter Ausgaben für Artikel-89-Maßnahmen), die Ausgaben für Agrardieselverbilligung und die Bundeszuschüsse für das agrarsoziale Sicherungssystem. Gebildet wurde jeweils ein Jahresdurchschnittswert, mit dem die Fördersituation von

1995 bis 2008 beschrieben wird[5]. Um eine regional differenzierte Darstellung für die vier Maßnahmen vornehmen zu können, waren für einige Maßnahmen Schätzungen und Hochrechnungen erforderlich.[6]

Karte 1 vermittelt ein Bild von der regionalen Verteilung der finanziellen Staatshilfen für den Agrarsektor in Deutschland differenziert nach Landkreisen und kreisfreien Städten.[7] Beschrieben werden die auf die Einwohner normierten Ausgaben (Pro-Kopf-Werte). Für die grafische Darstellung wurden vier Förderintensitätsstufen nach Quartilen gebildet. Für die 10 Landkreise mit der höchsten bzw. der niedrigsten Förderintensität wurden jeweils eine eigene Klasse gebildet. Ländliche Landkreise werden im Sinne der siedlungsstrukturellen Klassifikation des BBR in ländliche Kreise i. e. S. (Kreistyp 9: Ländliche Kreise geringerer Dichte + Kreistyp 8: Ländliche Kreise höherer Dichte) und in ländliche Kreise i. w. S. (Kreistyp 7: Ländliche Kreise verstädterte Räume + Kreistyp 4: Ländliche Kreise Agglomerationsräume) in den Karten unterlegt (BBR, 2008).

Der geringe Wertschöpfungsbeitrag des Agrarsektors in den Stadtstaaten und kreisfreien Städten und die dort vorzufindende hohe Einwohnerdichte führen in diesen Regionen zu einer geringen Pro-Kopf-Förderintensität. Damit partizipieren die Stadtstaaten und kreisfreien Städte sowie zum Teil auch die im engeren Umfeld der Kernstädte liegenden Kreise von den finanziellen Staatshilfen für den Agrarsektor am wenigsten. Flächenlandkreise mit einer vergleichbar niedrigen Förderintensität von unter 43 Euro je Einwohner sind eher die Ausnahme (Esslingen, Saarbrücken, Saarlouis und Neunkirchen). Als Regionen mit einer besonders niedrigen Förderintensität heben sich das Ruhrgebiet und der Großraum Frankfurt sowie das Saarland und große Teile in Baden-Württemberg ab. Im Süden, insbesondere in Bayern, sowie im Norden Deutschlands partizipieren die Einwohner von den finanziellen Staatshilfen für den Agrarsektor deutlich stärker. Gehäuft finden sich Landkreise mit einer Förderintensität in der Klasse zwischen 305 und 570 Euro je Einwohner. Die Förderbeträge liegen somit um rund das 10- bis 15-fache höher als in den Kreisen des untersten Quartils.



[1)] vgl. Fußnote 5

Quelle: Eigene Darstellung auf Grundlage der Verwaltungsgrenzen (2009) des Bundesamtes für Kartographie und Geodäsie sowie verschiedener Datenquellen.

Karte 1:

Regionale Verteilung der jahresdurchschnittlichen[1)] finanziellen Staatshilfen für den Agrarsektor in Euro je Einwohner in den Kreisen und kreisfreien Städten

Die 10 Kreise mit der höchsten Förderintensität (> 571 Euro je Einwohner) konzentrieren sich auf Kreise im Dreiländereck Niedersachsen, Brandenburg und Sachsen-Anhalt sowie auf vier Kreise in Bayern und den Landkreis Bitburg-Prüm in Rheinland-Pfalz. Bei Spitzenwerten von jahresdurchschnittlich gewährten Agrarhilfen in Höhe von rund 600 bis 700 Euro je Einwohner dürften in diesen Landkreisen relativ starke konsum- und investitionsinduzierte regionale Einkommenseffekte ausgehen, die für eine stabile und nachhaltige regionalwirtschaftliche Entwicklung von nicht zu unterschätzender Bedeutung sind. Der Förderbetrag der finanziellen Staatshilfen für den Agrarsektor in diesen Intensivförderkreisen liegt nur rund 200 Euro je Einwohner unter dem Förderniveau der jahresdurchschnittlichen gesamten finanziellen Staatshilfen der raumwirksamen Politikbereiche in den alten Bundesländern; in den neuen Bundesländern erreichen die Agrarhilfen der Landkreise mit der höchsten Förderintensität etwa 1/3 des Niveaus der gesamten finanziellen Staatshilfen (vgl. Tabelle 1).

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[5] Der Jahresdurchschnittswert basiert für den Bereich der Agrarsozialpolitik auf den Bundeszuschüssen der Jahre 1996 bis 2008, für die Agrardieselverbilligung auf den Ausgaben der Jahre 1995 bis 2007, für Maßnahmen der 2. Säule der GAP auf den für die Jahre 2005 bis 2013 hochgerechneten projizierten Ausgaben des Jahres 2008 sowie für die Maßnahmen der 1. Säule auf den Ausgaben für das Jahr 2008. In den Ausgaben der 2. Säule ist ein geschätzter Anteil für Artikel-89-Maßnahmen enthalten. Datengrundlage bilden Daten der Bundesanstalt für Landwirtschaft und Ernährung, Daten der amtlichen Statistik, der Agrarberichte, des Kieler Subventionsberichts, des LSV-Spitzenverbandes, des Agrar- und Umweltportals des Landwirtschaftsministeriums Schleswig-Holstein und des RAUMIS-Modells. Zur Datenaufbereitung und Methodik der finanziellen Staatshilfen des Agrarsektors siehe Plankl (2011).

[6] Während die Daten für die Maßnahmen der 1. und 2. Säule der GAP mithilfe der Postleitzahlen auf die Kreise generiert wurden, waren für die regionale Verteilung der Ausgaben für die Agrardieselverbilligung und die Bundeszuschüsse des agrarsozialen Sicherungssystems regionale Verteilungsmodelle erforderlich, um die Maßnahmen von der Bundesländerebene auf die Landkreise herunterzubrechen.

[7] Für die Bundesländer Brandenburg und Sachsen wurden die Werte auf die neue Kreisreform umgerechnet.

Tabelle 3:

Die 20 Landkreise (ohne kreisfreie Städte und ohne Kernstädte) mit den höchsten bzw. niedrigsten jahresdurchschnittlichen[1)] finanziellen Staatshilfen für den Agrarsektor in Euro je Einwohner

Name	finanzielle Staatshilfen in € je Einwohner“	Siedlungs-struktureller Kreistyp	Bundesland
Landkreise mit Höchstförderung			
Lüchow-Dannenberg	723	9	NI
Eifelkreis Bitburg-Prüm	698	7	RP
Nordfriesland	698	9	SH
Prignitz	672	9	BB
Straubing-Bogen	644	8	BY
Altmarkkreis Salzwedel	601	9	ST
Rottal-Inn	592	9	BY
Neustadt a.d.Aisch-Bad W.	585	9	BY
Wittmund	581	7	Ni
Dingolfing-Landau	575	8	BY
Ostallgäu	549	8	BY
Cham	546	7	BY
Cloppenburg	539	7	NI
Ansbach	529	8	BY
Stendal	525	9	ST
Müritz	521	9	MV
Rotenburg (Wümme)	520	4	NI
Tirschenreuth	515	9	BY
Emsland	487	8	NI
Unterallgäu	480	7	BY
Landkreise mit Niedrigstförderung			
Rhein-Sieg-Kreis	58	2	NW
Ludwigsburg	56	2	BW
Böblingen	55	2	BW
Saarpfalz-Kreis	55	2	SL
Märkischer Kreis	49	2	NW
Rastatt	47	2	BW
Rhein-Erft-Kreis	47	2	NW
Aachen	47	2	NW
Groß-Gerau	46	2	HE
Saarlouis	45	2	SL
München	45	2	BY
Rhein-Kreis Neuss	42	2	NW
Unna	41	2	NW
Hochtaunuskreis	41	2	HE
Rheinisch-Bergischer Kreis	34	2	NW
Recklinghausen	32	2	NW
Neunkirchen	32	2	SL
Esslingen	32	2	BW
Ennepe-Ruhr-Kreis	30	2	NW
Main-Taunus-Kreis	28	2	HE

[1)] Vergleiche Fußnote 5.

Erläuterung der siedlungsstrukturellen Kreistypen: 2 = hochverdichtete Kreise, 4 = Ländliche Kreise in Agglomerationsräumen, 7 = Ländliche Kreise verstädterter Räume, 8 = Ländliche Kreise höherer Dichte, 9 = Ländliche Kreise geringerer Dichte.

Erläuterung der Abkürzungen: BB = Brandenburg, BW = Baden-Württemberg, BY = Bayern, HE = Hessen, MV = Mecklenburg-Vorpommern, NI = Niedersachsen, NW = Nordrhein-Westfalen, RP = Rheinland-Pfalz, SH = Schleswig-Holstein, SL = Saarland, ST = Sachsen-Anhalt.

Quelle: Eigene Berechnungen.

In Tabelle 3 sind die 20 Flächenlandkreise mit der höchsten bzw. der niedrigsten Pro-Kopf-Agrarförderung gegenübergestellt. Bei den 20 Kreisen mit der niedrigsten Förderung handelt es sich ausschließlich um hoch verdichtete Kreise: neun Kreise aus Nordrhein-Westfalen, vier aus Baden-Württemberg, aber nur ein Landkreis aus Bayern. Bei den förderintensiven Landkreisen sind es zum Vergleich neun Kreise aus Bayern. Die restlichen 11 Kreise verteilen sich auf sechs Bundesländer, jeweils drei neue und drei alte Bundesländer. Ohne Ausnahme handelt es sich ausschließlich um ländliche Kreise und bei den ländlichen Kreisen überwiegen die Ländlichen Kreise mit hoher und geringer Dichte (Kreistypen 8+9). Vier Intensivförderkreise, Salzwedel, Müritz, Stendal und Prignitz kommen aus den neuen Bundesländern. Bei den Kreisen mit niedriger Förderintensität ist keiner aus den neuen Bundesländern vertreten.

Um die Unterschiede in der Förderintensität zwischen ländlichen und nicht ländlichen Kreisen deutlicher als in der Kartendarstellung erkennen zu können und gleichzeitig der Frage nachzugehen, ob die im ländlichen Raum lebende Bevölkerung stärker von den finanziellen Staatshilfen des Agrarsektors profitiert, wurde eine nach alten und neuen sowie nach nördlichen und südlichen Bundesländern differenzierte Auswertung durchgeführt (vgl. Tabelle 4)[8] . Danach wird deutlich, dass sowohl in der Summe aller ländlichen Kreise der alten als auch der neuen Bundesländer die Förderintensität deutlich höher ist als in den nicht ländlichen Landkreisen. In den alten Bundesländern liegt die Förderintensität etwa viermal, in den neuen Bundesländern sogar fünfmal so hoch. In den ländlichen Kreisen der alten Bundesländer ist die Förderintensität knapp 100 Euro je Einwohner höher als in den neuen Bundesländern. Bei den nicht ländlichen Kreisen liegt der Unterschied bei 30 Euro. Ländliche Kreise i. e. S. (Kreistypen 8+9) weisen eine höhere Förderintensität auf als die ländlichen Kreise der Agglomerationsräume und verstädterten Räume (Kreistypen 4+7). Der Unterschied in der Förderintensität fällt dabei in den alten Bundesländern mit 27 Euro je Einwohner im Vergleich zu 50 Euro je Einwohner in den neuen Bundesländern deutlicher geringer aus. Damit profitieren in den neuen Bundesländern die Einwohner der ländlichen Kreise i. e. S. relativ stärker von den finanziellen Staatshilfen des Agrarsektors. Insgesamt entsprechen die Ergebnisse den Erwartungen: Je ländlicher, desto höher die Förderung pro Einwohner.

Der geringe Anteil an nicht ländlichen Kreisen verhindert in den neuen Bundesländern einen Nord-Süd-Vergleich. Der Nord-Süd-Vergleich in den alten Bundesländern zeigt für die ländlichen Kreistypen 8+9 ein Nord-Süd- und für

8 Nördliche alte Bundesländer: Schleswig-Holstein, Niedersachsen, Hamburg, Bremen und Nordrhein-Westfalen; südliche alte Bundesländer: Hessen, Rheinland-Pfalz, Saarland, Bayern und Baden-Württemberg.

die ländlichen Kreistypen 4+7 sowie die nicht ländlichen Kreise ein Süd-Nord-Gefälle in der Förderintensität. Insgesamt machen die Ergebnisse deutlich, dass es durch die staatlichen Finanzhilfen für den Agrarsektor zu einer regionalen Umverteilung kommt, aus der die Einwohner der ländlichen Kreise im Durchschnitt einen größeren Nutzen im Sinne von höheren finanziellen Staatshilfen ziehen. In den alten Bundesländern ist jedoch zu beobachten, dass auch einige nicht ländliche Landkreise finanzielle Staatshilfen pro Kopf erzielen, die das Niveau der ländlichen Kreise erreichen (vgl. Karte 1). In Bayern trifft dies auf den Landkreis Pfaffenhofen, in Rheinland-Pfalz auf die Kreise Südliche Weinstrasse und Alzey-Worms, in Schleswig-Holstein auf Rendsburg-Eckernförde und in Niedersachsen auf die Landkreise Friesland, Aurich, Ammerland, Vechta, Osnabrück und Stade zu. Ländliche Kreise mit einer vergleichsweise geringen Förderintensität finden sich mit Ausnahme von Freudenstadt verstärkt in den neuen Bundesländern Brandenburg, Sachsen und Thüringen. Die beiden Bundesländer, Mecklenburg-Vorpommern und Brandenburg, die ausschließlich über ländliche Kreise verfügen, unterscheiden sich insofern, als Mecklenburg-Vorpommern eine vergleichsweise hohe und wenig differenzierte Förderintensität ausweist, während in Brandenburg die Förderintensität sehr stark zwischen den Landkreisen streut und mit Entfernung zum Agglomerationszentrum Berlin tendenziell die Förderintensität zunimmt.

Die nach ländlichen Regionen differenzierten Auswertungen (vgl. Tabelle 4) unterstreichen den bereits aus Karte 1 gewonnenen Eindruck, dass die Agrarförderung in der Summe aller vier berücksichtigten Maßnahmenbereiche der im ländlichen Raum lebenden Bevölkerung verstärkt zugutekommt. Abgesehen von der Ausgleichszulagenförderung in benachteiligten Gebieten und den Maßnahmen der Schwerpunkte 3 und 4 der 2. Säule der GAP, bei welchen es sich einerseits um eine gebietsspezifische Förderung handelt und andererseits die Maßnahmen gezielt dem ländlichen Raum zugeführt werden, kommt es durch die auf die landwirtwirtschaftlich genutzte Fläche bzw. Betriebe bezogenen Agrarfördermaßnahmen sowie durch die im ländlichen Raum geringere Einwohnerdichte zu einer höheren Förderintensität in ländlich geprägten Regionen. Da es sich bei der Darstellung der Förderintensität um die auf die Einwohner bezogene Förderintensität handelt, ist entsprechend dem Verbleib an regionalen Konsum- und Investitionsausgaben davon auszugehen, dass auch die in diesen Räumen lebenden Menschen außerhalb des Agrarsektors indirekt von den finanziellen Staatshilfen des Agrarsektors profitieren.

4 Regionale Verteilung der Ausgaben für Maßnahmen der 2. Säule

Mit der 2. Säule der GAP sollen die ländlichen Regionen unter Berücksichtigung ihrer unterschiedlichen Entwicklungspotenziale als Lebens- und Wirtschaftsräume erhalten und entwickelt werden. Dabei soll die Förderung zur Erreichung gleichwertiger Lebensverhältnisse in allen Teilen Deutschlands mehr als bisher auf die spezifischen regionalen Erfordernisse eingehen (BMELV, 2007b). Gemäß dieser Zielsetzung richtet sich die mit EU-, Bundes- und Landesmittel finanzierte Förderung der 2. Säule an ländliche Regionen. Um die Ausrichtung der Politik zur Entwicklung ländlicher Räume in Deutschland insgesamt überprüfen zu können, bedarf es einer für Deutschland flächendeckenden und nach ländlichen und nicht ländlichen Landkreisen differenzierten Situationsbeschreibung der regionalen Inanspruchnahme der Fördermaßnahmen.

Tabelle 4:

Jahresdurchschnittliche[1)] finanzielle Staatshilfen für den Agrarsektor in Euro je Einwohner in ländlichen und nicht ländlichen Kreisen und kreisfreien Städten der neuen und alten Bundesländer

Regionen	Finanzielle Staatshilfen für den Agrarsektor in € je Einwohner				
	Ländliche Kreise			Nicht ländliche Kreise	insgesamt
	Kreistypen 8+9	Kreistypen 4+7	insgesamt		
Alte Bundesländer-Nord	399	315	348	79	118
Alte Bundesländer-Süd	344	341	342	91	161
Alte Bundesländer insgesamt	358	331	344	85	141
Neue Bundesländer insgesamt	276	226	250	55	149
Deutschland insgesamt	328	293	310	80	142

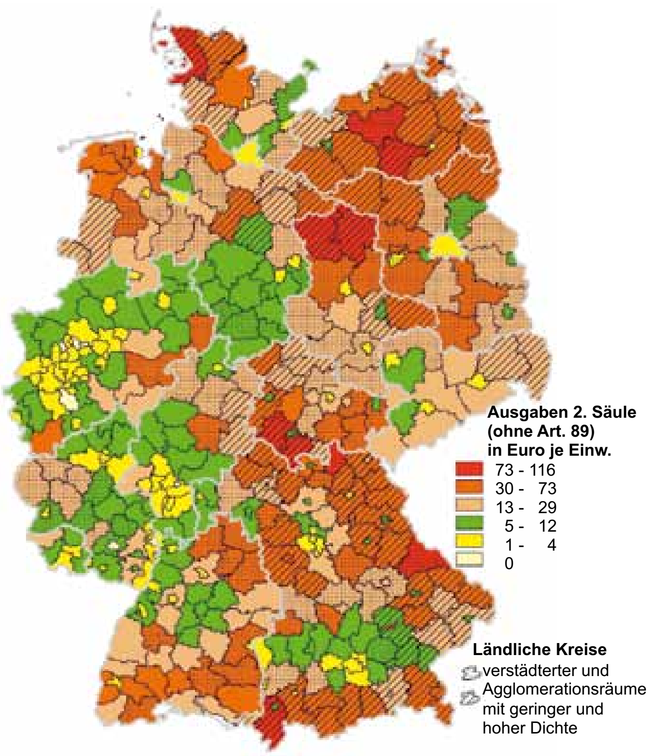
1) Vergleiche Fußnote 5.
Erläuterung der siedlungsstrukturellen Kreistypen: siehe Tabelle 2.

Quelle: Eigene Berechnungen.

Durch die auf Bundesländerebene konzipierten Förderprogramme zur Entwicklung Ländlicher Räume und das auf der Landesebene etablierte Monitoring- und Bewertungsverfahren fehlte bis zur laufenden Förderperiode 2007 bis 2013 eine vollständige flächendeckende Übersicht der regionalen Inanspruchnahme dieser Maßnahmen auf Landkreisebene. Für die Beurteilung erschwerend kam hinzu, dass auch für die Maßnahmen der GAK, welche die Basis für die Agrarstrukturförderung und die Förderung der ländlichen Entwicklung bilden, nur die regionale Verteilung der Mittel nach Bundesländern vorliegt.

Mit den bei der Bundesanstalt für Landwirtschaft und Ernährung (BLE) gesammelten Finanzdaten hat sich die Situation inzwischen verbessert. Nunmehr ist es möglich, für die ersten Jahre der aktuellen Förderperiode ein regionales Verteilungsbild der finanziellen Mittel für die Maßnahmen der 2. Säule zu beschreiben. Wenn auch die ausschließlich mit nationalen Mitteln finanzierten sogenannten Artikel-89-Maßnahmen in dem Datensatz fehlen, die Inanspruchnahme in den Jahren 2007 und 2008 das geplante Niveau noch nicht voll erreicht hat (Tietz, 2007) und eine Regionalisierung der Mittel nach den vier Schwerpunktachsen bzw. nach Einzelmaßnahmen mit den BLE-Daten nicht möglich ist, hat sich mit den zentral gesammelten Förderdaten der Grad der Transparenz entscheidend verbessert. Durch die verbesserte Datengrundlage dürfte es auch leichter möglich sein, die Ausrichtung der Politik an den regionalen im Vergleich zu den sektoralen Zielen zu überprüfen. Nach einer Zuordnung der Daten auf Landkreise mit Hilfe einer Schlüsselbrücke (Röder, 2010) lässt sich flächendeckend für Deutschland das regionale Verteilungsbild der 2. Säule-Maßnahmen nach Landkreisen und kreisfreien Städten generieren. Lediglich durch die Verbuchung der BLE-Daten am Ort des Zuwendungsempfängers und die Zuweisung von Zahlungen an zentrale Zuwendungsempfänger bestehen einige nicht zu eliminierende Einflussfaktoren, die möglicherweise zu einer Verzerrung führen (Grajewski, 2011).

Zur Abschätzung der relativen Bedeutung der Ausgaben für Maßnahmen der 2. Säule der GAP an den gesamten finanziellen Staatshilfen des Agrarsektors bzw. an den gesamten raumwirksamen finanziellen Staatshilfen würden die im Jahr 2008 noch nicht in vollem Umfang in Anspruch genommenen Ausgaben zu einer Unterschätzung führen. Quantifizierungen auf der Basis der projizierten Ausgaben einschließlich der geschätzten Ausgaben für Artikel-89-Maßnahmen zeigen, dass bei jährlich rund 2 Mrd. Euro an öffentlichen Finanzmitteln für die Maßnahmen zur Förderung der Entwicklung ländlicher Räume der Anteil an den gesamten finanziellen Staatshilfen für den Agrarsektor im Durchschnitt Deutschlands bei rund 17 % liegt. Gemessen an den gesamten regionalwirtschaftlich bedeutenden Finanzhilfen (vgl. Tabelle 1) liegt der Anteil bei 2 %. Die durchschnittliche Förderintensität für die Maßnahmen der 2. Säule liegt bei rund 24 Euro je Einwohner.



Quelle: Eigene Darstellung auf Grundlage der Verwaltungsgrenzen (2009) des Bundesamtes für Kartographie und Geodäsie sowie verschiedener Datenquellen.

Karte 2:

Regionale Verteilung der finanziellen Staatshilfen der 2. Säule der GAP ohne Artikel-89-Maßnahmen in Euro je Einwohner in den Kreisen und kreisfreien Städten im Jahr 2008

Zur Darstellung der regionalen Unterschiede der Ausgaben der Maßnahmen der 2. Säule der GAP wird in Karte 2 auf die Daten für das Jahr 2008 zurückgegriffen. Da hierin Artikel-89-Maßnahmen unberücksichtigt sind und die Inanspruchnahme noch nicht das geplante Niveau erreicht hat, liegen die insgesamt verausgabten Fördergelder bei rund 1,1 Mrd. Euro. Zur Messung der Förderintensität wurde wie bereits bei den Gesamtagrarhilfen eine Normierung der Mittel auf die Einwohner vorgenommen. Danach liegt die Pro-Kopf-Förderintensität bei knapp 14 Euro je Einwohner. Die Karte macht deutliche regionale Unterschiede in der Förderintensität in Deutschland sichtbar. Räume mit einer hohen Förderintensität sind der Norden von Deutschland und dort insbesondere der Raum Mecklenburg-Vorpommern, der äußerste Süden sowie der nordöstliche Teil Bayerns und Teile von Baden-Württemberg und Thüringen. Kreise mit einer unterhalb des Medianwertes liegenden Förderung liegen überwiegend in den alten Bundesländern. Als Niedrigfördergebiete heben sich das bevölkerungsreiche Nordrhein-Westfalen, der Süden Niedersachsens, der Großraum um Frankfurt, die Region um Stuttgart und die Voralpenlandkreise in Bayern hervor. Während in einigen Bundesländern die Unterschiede in der Förderintensität auf unterschiedlichem Niveau eher gering ausfallen (siehe Mecklenburg-Vorpommern, Rheinland-Pfalz) gibt es Bundesländer wie Bayern, Baden-Württemberg und Niedersachsen, wo die Förderintensität stark variiert. Von den 10 Landkreisen mit der höchsten Förderung liegen vier in zwei der alten Bundesländer (Bayern und Schleswig-Holstein) und sechs in den neuen Bundesländern Mecklenburg-Vorpommern, Sachsen-Anhalt und Thüringen. Kreise mit niedriger Förderintensität sind neben Berlin ausschließlich kreisfreie Städte.

Insgesamt ist auch bei den Maßnahmen der 2. Säule in den ländlichen Kreisen eine deutlich höhere Pro-Kopf-Förderintensität zu beobachten, mit 31 Euro je Einwohner liegt sie etwa vier- bis fünfmal so hoch wie die Förderintensität in den nicht ländlichen Kreisen (vgl. Tabelle 5). In den alten und neuen Bundesländer sowie den nördlichen und südlichen Kreisen der alten Bundesländer liegt die Förderintensität in den ländlichen Kreisen i. e. S. (Kreistypen 8+9) zwischen sechs und 10 Euro je Einwohner höher als in den ländlichen Kreisen der Typen 4+7. In den einzelnen Bundesländern sind die Förderunterschiede innerhalb der ländlichen sowie der nicht ländlichen Kreise sehr unterschiedlich. Beispielsweise streut in den ländlichen Kreisen Schleswig-Holsteins die Förderintensität zwischen Ostholstein mit 12 Euro je Einwohner und Nordfriesland mit 116 Euro je Einwohner, in Niedersachsen liegt die Minimum-Maximum-Streuung zwischen sechs Euro je Einwohner im Landkreis Celle und 64 in Lüchow-Dannenberg, in Bayern zwischen acht Euro je Einwohner in Mühldorf und 80 in Oberallgäu und in Brandenburg liegt die Differenz zwischen niedrigstem und höchstem Wert zwischen neun in Barnim und 51 Euro je Einwohner in Prignitz. Nicht weniger stark ausgeprägt ist die Streuung der Förderintensität in den nicht ländlichen Kreisen einzelner Bundesländer. Länder mit den größten Unterschieden in der Förderung ländlicher sowie nicht ländlicher Landkreise sind Bayern, Schleswig-Holstein und Niedersachsen. Obwohl ein überwiegender Teil der 2. Säule-Zahlungen flächen- und betriebsbezogen verteilt wird, kommt es durch die regionale Verteilung, insbesondere der Mittel für die Förderschwerpunkte 3 und 4 sowie durch den Einfluss der Bevölkerungsdichte zu einer deutlich höheren Zuweisung von Mitteln an ländliche Räume und damit zu regional induzierten Einkommenseffekten für die Einwohner in ländlichen Räumen. Die im Vergleich zur regionalen Verteilungssituation aller Agrarförderausgaben (Karte 1) in einigen Bundesländern nicht ganz so erwartungsgemäße Übereinstimmung zwischen hoher Förderintensität und ländlichen Kreistypen und niedriger Förderintensität und nicht ländlichen Räumen mag zunächst bei einer Maßnahme, die den Namen „Entwicklung ländlicher Räume“ trägt, überraschen. Es ist jedoch zu bedenken, dass die Maßnahmen im Förderschwerpunkt 1 „Verbesserung der Wettbewerbsfähigkeit“ und im Schwerpunkt 2 „Verbesserung der Umwelt und der Landwirtschaft“ im Gegensatz zu Schwerpunkt 3 „Lebensqualität im ländlichen Raum und Diversifizierung der ländlichen Wirtschaft“ auch keine expliziten regionalen Ziele verfolgen. Ferner ist grundsätzlich darauf hinzuweisen, dass die Ergebnisse der regionalen Verteilung der 2. Säule-Maßnahmen nach Landkreisen nur die nach dem Ort der Zuwendungsempfänger verteilten Mittel im Sinne der formalen regionalen Inzidenz beschreiben. Ob die finanziellen Staatshilfen für die Maßnahmen der 2. Säule auch innerhalb der Erstzuwenderregion konsumiert oder investiert werden oder es durch Import-Export-Verflechtungen zu Ausstrahlungseffekten in andere Regionen kommt, wird bei der regionalen formalen Inzidenz nicht ermittelt. Hierfür wäre eine effektive regionale Inzidenzanalyse durchzuführen (vgl. Färber, 2007).

Tabelle 5:

Finanziellen Staatshilfen der 2. Säule der GAP ohne Artikel-89-Maßnahmen in Euro je Einwohner in ländlichen und nicht ländlichen Kreisen und kreisfreien Städten der alten und neuen Bundesländer im Jahr 2008

Regionen	Ausgaben 2. Säule in € je Einwohner				
	Ländliche Kreise			Nicht ländliche Kreise	insgesamt
	Kreistypen 8+9	Kreistypen 4+7	insgesamt		
Alte Bundesländer-Nord	32	22	26	6	9
Alte Bundesländer-Süd	35	29	32	8	15
Alte Bundesländer insgesamt	34	26	30	7	12
Neue Bundesländer insgesamt	37	28	32	7	19
Deutschland insgesamt	35	27	31	7	13

Erläuterung der siedlungsstrukturellen Kreistypen: siehe Tabelle 2.

Quelle: Eigene Berechnungen.

5 Bedeutung der einzelnen finanziellen Staatshilfen des Agrarsektors in den ländlichen und nicht ländlichen Regionen

Durch welche der vier Maßnahmenbereiche der finanziellen Staatshilfen für den Agrarsektor ein stärkerer oder weniger starker Mittelfluss in ländliche Räume erfolgt, zeigt Tabelle 6. Danach sind deutliche Unterschiede zwischen den alten und neuen Bundesländern zu beobachten. In den ländlichen und nicht ländlichen Kreisen der neuen Bundesländer kommt den Ausgaben der 1. Säule der GAP mit einem Anteil von rund 2/3 die größte finanzielle Bedeutung bei. Die Ausgaben für die Agrardieselverbilligung haben in allen Kreistypen der alten und neuen Bundesländer mit rund 3 % nur eine geringe Bedeutung. Auf die gesamten Bundeszuschüsse des agrarsozialen Sicherungssystems entfallen in den alten Bundesländern rund 40 % der finanziellen Staatshilfen des Agrarsektors. In den südlichen ländlichen Kreisen der alten Bundesländer liegt der Anteil mit 43 % rund 11 %-Punkte höher als in den ländlichen Kreisen des Nordens. Zwischen ländlichen Kreisen insgesamt und den nicht ländlichen Kreisen besteht in den alten Bundesländern nur ein sehr geringer Unterschied im Anteil der einzelnen finanziellen Staatshilfen. Anders in den neuen Bundesländern, dort liegt der Anteil der Bundeszuschüsse für das agrarsoziale Sicherungssystem in den ländlichen Kreisen mit 8 % im Vergleich zu 10 % in den nicht ländlichen Kreisen niedriger. Insgesamt haben die Bundeszuschüsse für das agrarsoziale Sicherungssystem in den neuen Bundesländern systembedingt durch unterschiedlich hohe Entlastungsraten bei den landwirtschaftlichen Berufsgenossenschaften eine geringe Bedeutung. Deutliche regionale Unterschiede bestehen beim Anteil der staatlichen Ausgaben für die Maßnahmen der 2. Säule der GAP. In den neuen Bundesländern entfallen von den gesamten finanziellen Staatshilfen für den Agrarsektor rund ¼ auf die Maßnahmen der 2. Säule. In den nicht ländlichen Kreisen liegt entgegen den Erwartungen, der Anteil 2 %-Punkte höher. In den alten Bundesländern stellt sich die Situation so dar, dass erwartungsgemäß in den ländlichen Kreisen der Anteil der Maßnahmen der 2. Säule höher liegt als in den nicht ländlichen Kreisen. Dabei besteht ein deutlicher Unterschied zwischen den nördlichen und südlichen Bundesländern. Im Süden entfallen auf die Maßnahmen der 2. Säule mit 17 % knapp 4 %-Punkte mehr Ausgaben als in den nördlichen Bundesländern. Die größten Unterschiede zwischen Nord und Süd in den alten Bundesländern sind bei den Ausgaben der 1. Säule der GAP bzw. den Bundeszuschüssen für das agrarsoziale Sicherungssystem zu beobachten.

Um die Bedeutung der Ausgaben der 2. Säule als Politik für den ländlichen Raum hervorzuheben, wird in Karte 3 der Anteil der Mittel für die Maßnahmen der 2. Säule an den gesamten finanziellen Staatshilfen des Agrarsektors in

Tabelle 6:

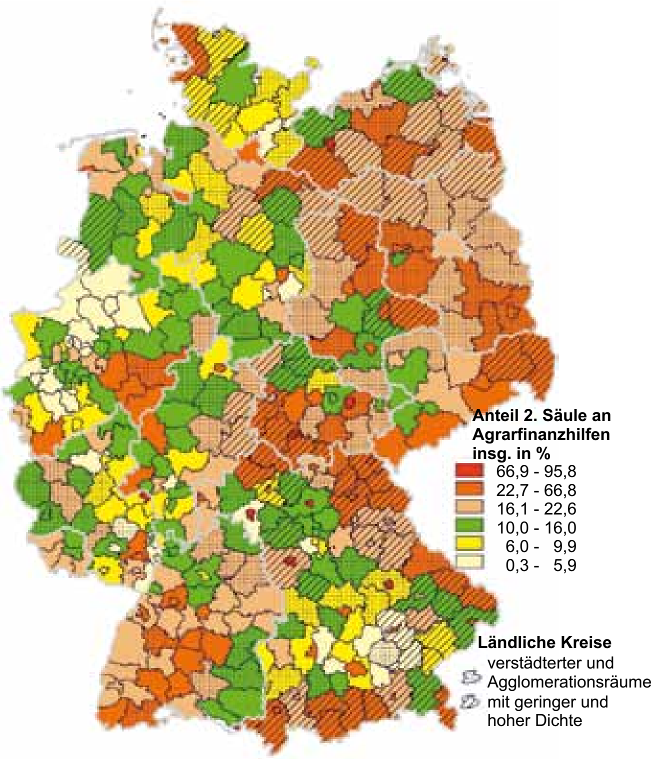
Verteilung der jahresdurchschnittlichen[1)] finanziellen Staatshilfen für den Agrarsektor nach Maßnahmen in den ländlichen und nicht ländlichen Kreisen und kreisfreien Städten der alten und neuen Bundesländer in %

Regionen	Anteil in %			
	1. Säule	2. Säule	Agrardieselverbilligung	Agrarsozialpolitik
Alte Bundesländer				
Ländliche Kreise (Kreistypen 4+7+8+9) insgesamt	42	16	3	39
Ländliche Kreise (Kreistypen 4+7+8+9) Nord	52	13	3	32
Ländliche Kreise (Kreistypen 4+7+8+9) Süd	37	17	2	43
Nicht ländliche Kreise	43	14	3	40
Neue Bundesländer				
Ländliche Kreise (Kreistypen 4+7+8+9)	67	22	3	8
Nicht ländliche Kreise	63	24	2	10
Deutschland				
Ländliche Kreise (Kreistypen 4+7+8+9)	50	18	3	30
Nicht ländliche Kreise	45	15	3	37

[1)] Vergleiche Fußnote 5.
Erläuterung der siedlungsstrukturellen Kreistypen: siehe Tabelle 2.

Quelle: Eigenen Berechnungen.

seiner regionalen Differenziertheit dargestellt. Im Vergleich zur regionalen Verteilung der Maßnahmen der 2. Säule je Einwohner (vgl. Karte 2) zeigen sich bei der Bedeutung der Maßnahmen der 2. Säule an den gesamten finanziellen Staatshilfen für den Agrarsektor weniger regional ausgeprägte Verteilungsunterschiede zwischen den neuen und alten Bundesländern sowie zwischen Bayern und Schleswig-Holstein zum Rest der alten Bundesländer.
Die Bedeutung der gesamten finanziellen Staatshilfen für den Agrarsektor in den ländlichen Kreisen wird besonders dann deutlich, wenn man den Finanzanteil mit dem Anteil der jeweiligen Einwohner bzw. der Fläche vergleicht (vgl. Tabelle 7). Auf die gesamten ländlichen Kreise der alten Bundesländer (Kreistypen 4+7+8+9) entfallen rund 17 % der Einwohner Deutschlands und rund 34 % des Gesamtfläche Deutschlands. Von den gesamten finanziellen Staatshilfen des Agrarsektors erhalten sie jedoch 41 %. Dies erklärt die vergleichsweise hohen Förderintensitäten in Karte 1. In den neuen Bundesländern entfallen auf die ländlichen Kreise 10 % der Einwohner Deutschlands, aber 18 % der finanziellen Staatshilfen des Agrarsektors. Der Vergleich des Anteils der Einwohner mit dem Anteil der finanziellen Staatshilfen in den nicht ländlichen Kreisen der alten sowie der neuen Bundesländer macht deutlich, dass die nicht ländlichen Kreise und kreisfreien Städte unterproportional zu den Einwohnern von den finanziellen Staatshilfen für den Agrarsektor profitieren.



[1)] vgl. Fußnote 5
Quelle: Eigene Darstellung auf Grundlage der Verwaltungsgrenzen (2009) des Bundesamtes für Kartographie und Geodäsie sowie verschiedener Datenquellen.

Karte 3:

Anteil der öffentlichen Ausgaben für Maßnahmen der 2. Säule der GAP an den gesamten finanziellen Staatshilfen des Agrarsektors[1)] (1. und 2. Säule der GAP, Agrardieselverbilligung und Bundeszuschüsse des agrarsozialen Sicherungssystems) in den Kreisen und kreisfreien Städten

Tabelle 7:

Verteilung der finanziellen Staatshilfen für den Agrarsektor, der Einwohner und der Fläche nach ländlichen und nicht ländlichen Regionen der alten und neuen Bundesländer in %

Regionen	%-Verteilung der ...		
	finanzielle Staatshilfen	Einwohner	Fläche
Alte Bundesländer			
Ländliche Kreise (Kreistypen 4+7+8+9) insgesamt	41	17	34
Ländliche Kreise (Kreistypen 4+7+8+9) Nord	14	6	12
Ländliche Kreise (Kreistypen 4+7+8+9) Süd	28	12	23
Nicht ländliche Kreise	37	62	35
Neue Bundesländer			
Ländliche Kreise (Kreistypen 4+7+8+9)	18	10	25
Nicht ländliche Kreise	4	11	5
Deutschland	100	100	100

Erläuterung der siedlungsstrukturellen Kreistypen: siehe Tabelle 2.

Quelle: Eigenen Berechnungen.

6 Resümee

Die finanziellen Staatshilfen für den Agrarsektor stellen sich in weiten Bereichen als eine Förderung dar, die den ländlichen Räumen bzw. in Teilen den dort lebenden Menschen zugutekommt. Ursächlich dafür ist die für große Bereiche der Agrarfördermaßnahmen erfolgte Verteilung der finanziellen Staatshilfen nach der Fläche und den Betrieben sowie der teils regional gezielte Einsatz mancher Agrarfördermaßnahmen, welche bei einer Betrachtung der auf die Einwohner bezogenen finanziellen Staatshilfen des Agrarsektors das regionale Verteilungsbild bestimmen. Für eine regionalwirtschaftliche Bewertung der finanziellen Staatshilfen des Agrarsektors sind die Erkenntnisse der deskriptiven Analyse jedoch noch nicht hinreichend. Es fehlen die von den Agrarausgaben ausgehenden effektiven regionalen Wirkungen. Immer ist auch zu berücksichtigen, dass Finanzhilfen von den Wirtschaftssubjekten zuvor zu erwirtschaften sind und dass hiermit meist eine Umverteilung zulasten der wirtschaftlich erfolgreichen Regionen einhergeht. Fragen, was kommt in der Region an und was verbleibt in der Region, wie wirken sich die Umverteilungen in den anderen Regionen aus und kommt es zu einer gesamtwirtschaftlichen Mehrung von Wohlstand, bleiben daher ein zentraler regionalwissenschaftlicher Forschungsgegenstand. Der Berücksichtigung der Agrarfördermaßnahmen ist aufgrund ihrer regional- und raumwirtschaftlichen Bedeutung und ihrer relativen Bedeutung zu den anderen raumwirksamen Maßnahmen in regionalwirtschaftlichen Fragestellungen und Untersuchungen ein vermehrtes Gewicht zu geben. Die regionalwirtschaftliche Bedeutung der Agrarpolitik ausschließlich am geringen gesamtwirtschaftlichen Beschäftigtenanteil und/oder Wertschöpfungsanteil der Landwirtschaft zu messen ist jedoch zu kurz gegriffen und vernachlässigt neben den Einkommenseffekten der Agrarförderung die Verflechtung des originären Agrarsektors mit den vor- und nachgelagerten Wirtschaftsbereichen und berücksichtigt nicht hinreichend die durch den Agrarsektor erbrachten gesellschaftlichen Leistungen.

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Biodiversity and Organic farming: What do we know?

Gerold Rahmann*

Abstract

The number of studies on organic farming and biodiversity increased significantly within the last years. Meanwhile organic farming has been recognised as a field with scientific relevance. About 19,000 publications were found in the Web of Science (www.isiknowledge.com) using Endnote® software with the wording "organic farming", and out of these about 1,200 were published by German scientists (6 %). In total 766 publications of these papers contained also the word "biodiversity" (3.5 %). Half of them were published during the last five years, and are mostly authored by Europeans. A meta-data analysis of these 766 scientific papers has been carried out to answer the question whether organic farming has an advantage for biodiversity in comparison to conventional farming systems.

327 out of 396 relevant results found a higher degree of biodiversity in organic farming when compared to conventional farming. In 56 papers (14 %) no difference was verified, and in 13 contributions (3 %) organic farming yielded less biodiversity (7 of them for soil invertebrates).

Thus it may be concluded that organic farming produces more biodiversity. Research gaps still exist for the understanding of functional biodiversity and ecosystem impact which comprise soil biota, landscape (ecosystem and habitat) and genetic biodiversity on agricultural land in natural habitats. In addition, more information is required about biodiversity of farming systems in non-European regions, particularly in the tropics and sub-tropics.

Keywords: Agri-environmental schemes, organic farming, biodiversity, integration, long-term field studies, segregation

Zusammenfassung:

Biodiversität und Ökologischer Landbau – Was wissen wir?

In den letzten Jahren sind eine Vielzahl von neuen Studien zum Ökologischen Landbau und Biodiversität veröffentlicht worden. Der Ökologische Landbau hat als wissenschaftliches Objekt an Bedeutung gewonnen. Im web of science (www.isiknowledge.com) wurden mit dem Quellenrechercheprogramm Endnote® unter dem Stichwort "organic farming" 19.000 Quellen gefunden, davon 1.200 (6 %) aus Deutschland. Mit der ergänzenden Einschränkung "biodiversity" waren es immer noch 766 Quellen (3,5 %), wovon die Hälfte erst in den letzten fünf Jahren veröffentlicht wurde, vorwiegend aus Europa. In einer Metaanalyse wurden diese 766 Quellen auf ihre Aussagen bezüglich der Bedeutung des Ökologischen Landbaus für die Biodiversität untersucht.

Es konnten 396 Bewertungen verwendet warden. 327 (83 %) der Bewertungen stellten fest, dass der Ökologische Landbau mehr Biodiversität aufweisst als der konventionelle Landbau. Weitere 56 (14 %) der Bewertungen waren indifferent und nur 13 (3 %; davon 7 alleine im Bereich des Bodenlebens) stellten fest, dass die Biodiversität im Ökologischen Landbau niedriger als im konventionellen Landbau ist.

Zusammenfassend kann aus dieser Metaanalyse geschlossen werden, dass der Ökologische Landbau förderlich für die Biodiversität ist. Die wissenschaftliche Arbeit sollte sich verstärkt um die Lücken des Wissens zur funktionellen Biodiversität und landwirtschaftliche Systeme kümmern. Das Bodenleben, die Landschaft (Ökosystem, Habitate) sowie die genetische agro- und natürliche Biodiversität sind dabei hervorzuheben. Auch fehlt es an Wissen über die Wirkung des Ökolandbaus auf die Biodiversität tropischer oder sub-tropischer Agrozonen (vor allem außerhalb von Europa).

Schlüsselworte: Agrarumweltmaßnahmen, Ökologischer Landbau, Biodiversität, Integration, Langzeit Feldstudien, Segregation

* Johann Heinrich von Thünen Institute (vTI), Federal Research Institute for Rural Areas, Forestry and Fisheries, Institute of Organic Farming, Trenthorst 32, 23847 Westerau, Germany, gerold.rahmann@vti.bund.de

1 Introduction

Biodiversity is one of the most important resources on earth, and human activities endanger the total number of species. Large numbers are already extinct or close to being erased. At the Rio-conference 1992, the United Nations agreed to reduce biodiversity losses to zero in 2010. The goals have not been reached. Farming (intensification and land use change) are main reasons for biodiversity losses, but agriculture can also protect and enhance biodiversity. Several strategies have been developed to produce food and protect biodiversity. Organic farming is considered an environmentally-friendly form of food production and receives agri-environmental payments for the protection of biodiversity. But does organic farming live up to this expectation? A lot of scientific efforts have been made to answer this question. The presented meta-data analysis was made to give an up-to-date evaluation of the state of the art.

2 The background

Biodiversity is defined as the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Reference). This biodiversity is threatened by human activities. Land use changes, degradation, pollution, climate change, and desertification and last but not least human population growth enforced the loss of biodiversity by factor 100 to 1,000 when compared to natural extinction. In 1992, the United Nations agreed to rescue the world's biodiversity. The Convention of Biological Diversity (CBD: 192 countries and the European Union) is one of the three Rio conventions. "The target agreed by the world's Governments in 2002 [Rio+10 summit in Johannesburg; GR], "*to achieve by 2010 a* significant *reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth",* has not been met. This disappointing conclusion is the introduction of the "Global Biodiversity outlook 3 of the United Nations in 2010", the year of biodiversity. This fatal situation needs to be faced though more than 170 countries (87 % of the Parties to the Convention, including Germany and the European Union) implemented national biodiversity strategies and action plans (Convention of Biological Diversity (CBD), 2010).

It is a fact that the world's biodiversity is still decreasing. The global Living Planet Index (LPI)[1] (WWF, 2010) has declined by more than 30 % since 1970. While the Tropical LPI declined by almost 60 %, the Temperate LPI [including Germany] increased by 15 %. Obviously, the efforts to protect environment and nature in temperate climates (mainly developed countries of the western world) have been successful after substantial declines in the past. About 1.75 million species are described worldwide but they are probably only a small share of the true total number (estimates provide a number of up to 13 million species; CBD, 2010).

In Germany, 48,000 animal species are described (Anonymous, 2011a), and 3,600 different plants can be found of which 2,800 are indigenous (Bundesamt für Naturschutz (BfN) ,2007). These figures include 77 tree species; 111 shrubs; 33,305 insects; 4,000 bacteria (estimations are 1 million bacteria species exist); 703 vertebrates with 100 mammals; 256 bird species; 14 reptiles, and 21 amphibians. Most of the 3001 higher plant and animal species are endangered because of land use changes and land use intensification (Rahmann, 2000). Among the European countries, losses in biodiversity are highest in Germany. About 28 % of the flora species and even more animal species (44 % of the birds, 51 % of the mammals, 61 % of ants, and 52 % of bees) are extinct or endangered (Anonymous, 2011b; BfN, 2008).

Agro-biodiversity is an important part of the world biodiversity. From the 250,000 worldwide described plant species, about 30,000 are edible, and about 7,000 are currently used for consumption. Not more than 30 species comprise more than 95 % of the food composition. And it is only three species (rice, wheat, corn) which supply more than 50 % of today's human food (Bundesanstalt für Landwirtschaft und Ernährung (BLE-BEKO), 2008). About 75 % of the genetic diversity of cultivated plants is already extinct (genetic erosion). Particularly fruits and vegetables species and varieties are endangered (Anonymous, 2011c). Crop production dominates the land use of many countries of the world. In Germany more than 50 % of the land surface is used for agriculture. Only a small number of different crop species are planted: A total of 27 % of the arable land is used for wheat, 17 % for barley, 15 % for corn, 12 % for oilseed rape, 4 % for rye so that only a quarter of the land is cultivated with any other plant. Counterproductive in terms of biodiversity is that crops are regularly cultivated in monoculture. The use of pesticides causes a change of the habitat and reduce/eradicate wild plants and wild animal biodiversity on a regional scale.

A similar trend can be observed in pens. More than 25 animal species are domesticated but only 11 of them are of economic relevance. Human selection has created a large number of different breeds. Many livestock breeds are endangered, especially sheep and goat breeds (Sambraus, 1999; www.g-e-h.de).The FAO registered more

[1] The Living Planet Index tracks nearly 4,000 populations of 241 fish, 83 amphibian, 40 reptile, 811 bird and 302 mammal species (WWF, 2010).

than 7,600 different breeds worldwide (FAO, 2007), and more than 1,500 of them are endangered.

The protection and backing of biodiversity is one of the main challenges of farming. Even before public laws enforced protection of wild plants and animals, organic farming had declared the aim to protect the environment and biodiversity in the first version of principles (IFOAM, 1980; www.ifoam.org).

One of the four principles of organic farming is defined by the International Federation of Organic Agricultural Movement (IFOAM, 2007): "*The Principle of Ecology: Organic Agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them. […] Organic agriculture should attain ecological balance through the design of farming systems, establishment of habitats and maintenance of genetic and agricultural diversity. Those who produce, process, trade, or consume organic products should protect and benefit the common environment including landscapes, climate, habitats, biodiversity, air and water.*"

The preamble of the EU regulation 834/2007 confirms the IFOAM principle: "Organic production is an overall system of farm management and food production that combines best environmental practices, a high level of biodiversity, the preservation of natural resources, the application of high animal welfare standards and a production method in line with the preference of certain consumers for products produced using natural substances and processes." In Article 3 (Objectives and principles for organic production) is fixed that "Organic production shall pursue the following general objectives: (a) establish a sustainable management system for agriculture that: (i) respects nature's systems and cycles and sustains and enhances the health of soil, water, plants and animals and the balance between them; (ii) contributes to a high level of biological diversity;" This includes soil and aquatic biodiversity (article 5 (a) (n) as well as farm crop and livestock diversity (889/2008 introduction (8)).

In contrast to the segregation strategy of conventional farming (production or protection), biodiversity is an integral component of organic farming (production and protection) (Rahmann et al 2006; Schnug et al., 2008). Therefore wild plants, livestock and agricultural biodiversity are found as co-products of the farming activity. The use of herbicides (but also other pesticides) is prohibited which protects the natural flora and fauna. Only manual, mechanical and heat measures are permitted for weed control. Wild fauna such as insects, snails, beetles, and spiders can be controlled through biotechnological measures (traps, lime, etc.) and natural insecticides (Annex II of 889/2008/EU) (Kühne et al., 2006).

Organic farming is based on norms which are in force worldwide (IFOAM, 2005). Organic production is expanding continuously and is practiced in more than 160 countries (of a total of 195 countries; in the year 2000 only 86 countries were documented with organic production). In 2007, more than 1,800,000 farms (677,000 organic farms only in India) manage about 38 million hectares farmland organically with certification (0.9 % of total agricultural farmland; plus 42 million hectare wild collection area). 2/3 of the world's organic farmland is grassland (Willer et al., 2011).

Europe was and is the most driving continent in the development and establishment of organic farming. One quarter of the world's organic farm land is in Europe (200,000 farms, 7.8 million hectares, 1.9 % share of total farmland). In the European Union (EU27) about 180,000 farms manage 7.2 million hectares land organically (4 % of the total farmland; 2007) and generate produce worth 16.8 billion Euros (2008). With 5.9 billion Euros (2010), Germany has the biggest organic market in Europe. The market share of organic products in the German food market is about 3 %, about half of the Danish market share with 6.7 %, and Austria with 5.7 %. The world organic purchases are 6 Euro per capita and year (2009). In the USA, about 50 Euro c^{-1} yr^{1} were spent in 2008 per capita. With 26 Euro c^{-1} yr^{1} the organic purchases are less in the EU27. Danish citizens purchase about 132 Euro c^{-1} yr^{1}, while Germany is in the middle field with about 71 Euro c^{-1} yr^{1} (AMI, 2010). 94 % of the German consumers buy organic food but only 3 % of all German consumers are relevant for 39 % of all organic sales. These intensive buyers spend about 730 Euro per year and household on organic food products. This is 39 % of total food purchase of these households (BÖLW, 2011). The Second National Nutrition Study of Germany (MRI, 2008) found that organic frequent consumers have a healthier lifestyle compared with non-organic consumers.

Currently the German farmers deliver about 50 % of the organic products for the German market, the other half is imported, mainly from other EU countries (BÖLW, 2011). The farmers get about 20 % of the market sales. That means, that 80 % of the value of organic products (final consumer spending) is earned in transport, processing and trade. This is comparable to conventional famers (AMI, 2010).

The implementation of official standards and regulations in the EU in 1992 (2092/91/EEC, 834/2007/EC and related regulations; http://ec.europa.eu/agriculture/organic/home_en) and the political support – European action plan for organic food and farming (since 2004) and national programmes like the German Bundespropgramm Ökologischer Landbau (www.bundesprogramm-oekolandbau.de) with more than 75 million Euro R&D fund since 2002 – were and are the main driving forces. The German speaking countries (DE, CH, AT) comprise the most relevant organic farming research in the world.

At the end of 2010, more than 21,000 German farms (5.6 % of total German farms) managed more than one million hectares farmland organically (5,6 % of total farmland) (BMELV, 2011). About 50 % of the German organic farmland is grassland, while total farmland comprises only 30 % in Germany. Grassland is important for biodiversity and has severely decreased in the last decades (Soussana and Duru, 2007), particularly in the last years in Germany in areas of biomass encroachment. The question is: Does organic farming fulfil the promise to protect the biodiversity better than non-organic (conventional) farming? A meta-data analysis was performed to answer this question.

3 Material and methods

The term "biodiversity" has many facets: It is commonly interpreted as species richness, only occasionally as the richness of varieties, cultivars or genetic expressions (e.g. micro-organisms) (Buchs, 2003; Buchs et al., 2003; Kasperczyk and Knickel, 2006). Not all papers gave clear answers on how to measure biodiversity. Classical ecology indexes were used to determine richness (S), but biodiversity (H') and dominance (D) were sometimes missing in the studies (Crowder et al., 2010). The impact of alpha (within-field level), beta (between-field level) and gamma diversity (landscape-level) is an important criterion (Rundlof et al., 2008). Here, it is necessary to evaluate and compare cultivation intensities, landscapes, micro-climate and agro-environments to respect the sensitivity of the biodiversity as an indicator of management.

The meta-data analysis was performed on the basis of scientific publications listed in the Web of Science and 'grey literature' in March 2011. The scientific papers are identified through a online database check in the Web of Science (www.isiknowledge.com), using Endnote® as the search and citation software, the online publication and project database organic eprints (http://orgprints.org) and grey literature in google (www.google.com), all under the search words "organic farming," "biodiversity", "[year]" and "[country]" in March 2011 (Table 1). In addition, the proceedings of the main scientific conferences of the organic sector in German speaking countries have been assessed as these papers are not listed in ISI.

Table 1:
Results of the web search "Organic farming", "biodiversity", "[year]", "[country]"

Results	**Web of Science** (Endnote® search March 2011)	**Organic eprints** (March 2011)	**Google** (x1.000)
"biodiversity"	97,215	n.a.	16,700
"Organic farming"	19.158	10.876**	8.860
"Organic farming", "Germany":	1.276	2.923**	7.740
"Organic farming", "biodiversity":	766	96***	3.390
- Year of publication:			
< 1991	0	0	142
1991 – 1995	17	1	145
1996 – 2000	78	3	142
2001 – 2005	250	37	530
2006 – 2011	421	55	2.010
- selected countries, continents:			
Germany	44	35	672
European Union	287*	83	1.978
USA, Canada	38+14	3+0	497
India	31	3	161
China	10	1	155
Australia, New Zealand	10+6	0	188
Africa	15	1	166
Country not specified	311	5	n.a.

* EU27 including Germany
** Including projects and institutions as dataset beside publication
*** Only publications

4 Results

4.1 The search results

In the last years the number of studies on organic farming and biodiversity increased significantly (Table 1). Despite the relatively new serious recognition of the organic system as a field of scientific relevance in the scientific world, about 19,000 publications were found in the Web of Science (www.isiknowledge.com) under the word of "organic farming". Out of these papers 1,200 were from Germany (6 %). 766 publications were found with the second search word "biodiversity" (3.5 %); half of them were published in the last five years by European researchers. This data set includes papers of the main international organic farming conferences.

In contrast to ISI listed data banks in the Web of Science it is usually hard to find grey literature. These papers may well meet scientific standards but miss a scientific platform for publication (e. g. diploma thesis, reports). The data bank http://orgprints.org was established in 2001 by the Danish DARCOF (today ICROFS) and joint by FiBL and BÖL to give grey organic farming papers a web-based source. All international and European organic conferences use the web platform for submission of papers (Table 2). Nowadays this organic farming databank has more than 10,000 entries. The majority of papers is from Europe, with about one third from Germany. A total of 1,154 submissions deal with environmental aspects, but only 526 publications focus on the subject "biodiversity and ecosystem service." 96 publications concentrate exclusively on biodiversity (1 %). The main activities of organic farming research are in the field of development of organic farming, while less attention has been paid to enhancing and strengthening sustainability (10 %). One reason is topic of the organic farming conference.

The Google search brought too many results without relevance to this study. This source was not considered for further analysis. However, it gives an impression about the importance of this topic in the web. The proceedings of the most important scientific conferences of organic farming proved to be the best source to get an overview of main research topics and the relevance of biodiversity in scientific studies. At the moment biodiversity is still a minor topic as only 105 papers dedicated their research to thus field of research (Table 1). This equals 4 % of all papers.

4.2 Meta-analysis of ISI listed papers

The meta-data analysis tried to answer the question, whether organic farming benefits biodiversity. From 766 studies found with Endnote® in Web of Science using the key words "organic farming" and "biodiversity," nearly half of the references (343) could be used for the assessment, 423 had to be rejected (Table 3). Because some studies have assessed more than one species, multiple answers were given. Thus some studies are cited more than once (total citations = 396). Not all studies made clear comparisons between organic and conventional farming systems (Pimentel et al., 2005; Pimpini et al., 2005). Nevertheless, the meta-data analysis comes to the unequivocal conclu-

Table 2:
Proceedings of the scientific conferences of organic farming in the last 10 years, published under http://orgprints.org

Selected scientific Organic Farming conferences	Place	Year	Papers total	Papers Biodiversity
13st International IFOAM Scientific conference	Basel, CH	2000	500	19
6. Wissenschaftstagung Ökologischer Landbau[1]	Freising, DE	2001	116	10
14th IFOAM Organic World Congress	Victoria, CA	2002	294	13
7. Wissenschaftstagung Ökologischer Landbau[1]	Wien, AT	2003	214	7
1st ISOFAR conference[1]	Adelaide, AU	2005	141	5
8. Wissenschaftstagung Ökologischer Landbau[1]	Kassel, DE	2005	215	6
Joint Organic Conference	Odense, DK	2006	275	1
9. Wissenschaftstagung Ökologischer Landbau[1]	Hohenheim, DE	2007	245	19
2nd ISOFAR conference	Modena, IT	2008	385	15
10. Wissenschaftstagung Ökologischer Landbau[1]	Zürich, CH	2009	287	10
11. Wissenschaftstagung Ökologischer Landbau[1]	Gießen, DE	2011	209	6
Total			2,881	111

[1] The papers of the biannual German speaking organic farming conferences are not found with Endnote® in web of science (ISI). The papers of these conferences have been assessed additionally because of their relevance on a global scale.

sion that biodiversity is higher in organic farming than in conventional farming. 327 citations backed this result, 56 were not clear and only 13 suggested that biodiversity was lower under organic farming management (Table 3).

Table 3:

Impact of organic farming[1] on biodiversity in comparison to conventional farming (no. of citations in ISI listed publications[2])

Subject	More biodiversity	Unclear, indifferent	Less biodiversity
Landscape	28	5	0
Flora on arable land	61	3	0
Flora on grass land	20	5	0
Flora perennial land use[3]	12	1	2
Invertebrates	77	12	7
Vertebrates	26	5	0
Bacteria, yeast, pests	6	2	1
Soil biota	38	15	0
Agro-biodiversity	28	2	0
Biodiversity in general	31	6	3
Total	327	56	13

[1] This includes organic farming, wild plant collection, traditional farming under organic standards (without certification).
[2] Multiple citations of 343 used papers are possible due to different conclusions for different species.
[3] Perennial land use: vineyards, orchards, special biotopes are for example: orchards, hedges, ponds, farm buildings, paths, fences, forests or stone heaps, special buildings, plantation or facilities for nature (e. g., herb loops). They are assessed in the context of adjacent farming systems.
Source: Web of Science search using Endnote® in March 2011; see Annex 1)

Most of the 396 citations were from Europe (80 %; only EU27 72 %), North-America (6 %) and Latin-America (5 %) (Table 4). Important countries for comparative studies on biodiversity were UK (65 citations; 20 %), DE (51; 16 %), SE (30; 9 %), CH (27; 8 %), IT (24; 7 %), FR (23; 7 %), NL (21; 6 %), US (20; 6 %) and ES (18; 6 %) (McLaughlin and Mineau, 1995).

Table 4:

Origin of the citations[1] about comparative studies of organic and conventional farming on biodiversity in different land use systems

Region	more	unclear	less	Total
Europe (from EU27)	258 (228)	48 (47)	11 (11)	317 (286)
North America	20	4	1	25
Latin America	16	3	0	19
Asia	11	0	0	11
Africa	4	0	0	4
Oceania	9	1	1	11
miscellaneous	9	0	0	9
Total	327	56	13	396

[1] Multiple citations of 343 used papers are possible due to different conclusions for different species.
Source: web of science search using Endnote® in March 2011; see Annex 1)

Organic farming was in favour for all species. The restricted use of pesticides and low nutrient input in organic farming were identified as main factors for a higher biodiversity of flora and fauna was usually (Frost and Ardeshir, 2004). Agro-biodiversity and landscape architecture were less often identified as key parameters for biodiversity. Some flora and fauna have adapted on intensive conventional farming (high nutrient level in soils and high crop yields etc.): epigaeic spiders, birds, plants like *Urtica dioica* (Nettel) (Rydberg and Milberg, 2000). Usually these flora and fauna is not endangered.

4.3 Long term trials

It seems safe to assume that the influence of the land use management is best reflected and assessed in long-term field experiments. And all long-term field studies (BMELV, 2005) with the topic "organic versus conventional farming" (Raupp, 2009) confirm the advantage of organic farming to improve biodiversity (soil biota, flora, arthropods): Glenlea long-term rotation study in Canada (Entz et al., 2005); the DOC-trial in Switzerland (Pfiffner, 1996; Fliessbach et al., 2000; Mader et al., 2002); State Research Institute at Osiny in Poland (Feledyn-Szewczyk, 2008); Rodale Institute Farming Systems Trial (Hepperly et al., 2006); Ekhaga Experimental Farm in Sweden (Lundkvist et al., 2008); Trenthorst organic farming system comparison study in Germany (Rahmann et al., 2006); Mediterranean Arable Systems Comparison Trial (MASCOT) and (MOLTE) in Italy (Migliorini and Vazzana, 2006; Mazzoncini et al., 2010).

4.4 Other meta-analysis

Pfiffner (1996) compiled 44 studies related to fauna richness of different land use management systems (Table 4). They concluded that fauna is more diverse on organic compared to conventional farm land. Bartram and Perkins (2003) found an advantage of organic farming in biodiversity in 33 UK studies, too. Lynch (2009) analysed studies from Canada and the USA and concluded that organic farming contributes to diversity of cropping, flora and habitat.

Bengtsson et al. (2005) found in their meta-data analysis of literature, published before December 2002 that organic farming increases species richness in general. Species richness was on average 30 % higher than in conventional farming systems. However, the results were variable among studies, and 16 % of them actually showed a negative effect of organic farming on species richness. On average, organisms were 50 % more abundant in organic farming systems, but the results were highly variable between studies and organism groups. Birds, predatory in-

Table 5:
Significant impact of organic farming on selected fauna

	Abundance of fauna No. of studies[1], where ...			Diversity of fauna species No. of studies[1], where ...		
Fauna group[2]	Organic more than conventional	Organic like conventional	Organic less than conventional	Organic more than conventional	Organic like conventional	Organic less than conventional
Earth worms	17	1	0	4	3	0
Ground beetles	13	2	0	6	2	0
Spiders	6	1	0	0	0	0
Millipedes	4	0	0	1	1	0
Bugs	2	1	0	1	1	0
Mites	2	0	1	1	1	0
Birds	5	0	0	1	1	0
Total	49	5	1	15	7	0

[1] Results of 44 studies; multiple answer possible.
[2] Most of these groups have important functions in agro-eco-systems.
Source: Pfiffner, 1996

sects, soil organisms and plants responded positively to organic farming, while non-predatory insects and pests did not. The positive effects of organic farming on abundance were verified at plot and field scale, but not on farm level.

Bugg (2002) found in studies conducted in the USA (Pennsylvania and North Dakota), UK (Wales and England) and Canada (Saskatchewan and Ontario) that organic farming and minimum tillage systems support a higher bird diversity and abundance than do conventional systems.

Mondelaers et al. (2009) performed a meta-data analysis of the peer reviewed literature comparing the environmental impacts of organic and conventional farming. They concluded that soils in organic farming systems have, on average, a higher content of organic matter and that organic farming contributes positively to agro-biodiversity (breeds used by the farmers) and natural biodiversity (wild life).

4.5 Agro-biodiversity

Biodiversity is not only defined for wild flora and fauna but also for cultivated crops (Mondelaers et al., 2009). While a higher diversity of cultivated and wild plants and associated fauna is found on grassland, arable land usually lacks biodiversity due to pesticide applications (Geiger et al., 2010). More than one third of the German surface is arable land and very often the cultivated crops are the only plants on these areas. There are about 40 different crops/crop groups cultivated on organic and conventional farms. These crops have different importance (abundance) and are not equally distributed over the area. Some crop species dominate, while others have only a very small share Table 5). The impact on agro-biodiversity can be measured through the inequality of the distribution. Using the statistical data from the cropping in organic farming, this is less equal than on conventional farming. The Gini coefficient[2] for organic farming is 0.69 and for conventional 0.82. The higher equality of organic farming can be easily explained. The crop rotation is broader than in conventional farming (a minimum of six versus a maximum of three different crops in the rotation).

5 Conclusions

In the presented comprehensive meta-data analysis, publications were assessed to prove whether organic farming has an advantage for biodiversity or not. This and other meta-analyses (Pfiffner, 1996; Bartram and Perkins, 2003; Bengtsson et al., 2005; Chamberlain et al., 2010) provide evidence that organic farming enhances and conserves biodiversity. A total of 766 ISI-listed publications were found with the search words "organic farming" and "biodiversity", 83 % from Europe. Half of them were published in the last five years. 396 papers could be used for the answer and 327 (83 %) of the citations (multi citations of the 343 papers were possible) found an advantage of organic farming for more biodiversity compared with conventional farming. 56 (14 %) citations were not sure or they found no difference and only 13 (3 %) came to the conclusion that organic farming has less biodiversity (7 of them for soil invertebrates).

[2] The Gini coefficient is defined as a ratio of the area on the Lorenz curve diagram and can be from "0" (very equal: all crops are cultivated on the same number of hectares) up to "1" (very unequal: nearly all hectares are used for only one crop).

Table 6:
Statistical data on cultivated crops in relation to the land use system in Germany (2008)

Crop	Organic (x1,000 ha)	% of organic	Conventional (x1,000 ha)	% of conventional	Percentage organic (%)
Farmland (utilised)	908	100.00	16,926	100,00	5.09
Cropland	385	42.40	12,103	71,50	3.08
Grassland	490	54.00	4,789	28,30	9.28
Mixed orchard/pasture	13	1.43	300	1,77	4.15
Permanent culture	12	1.32	200	1,18	5.66
Grain	188	20.70	6,518	38,50	2.80
Winter wheat	40	4.41	3,164	18,70	1.25
Summer wheat	7	0.72	43	0,25	13.10
Rye	52	5.73	737	4,35	6.59
Triticale	21	2.31	399	2,36	5.00
Winter barley	9	0.94	1,418	8,38	0.60
Summer barley	13	1.43	544	3,21	2.33
Dinkel	18	1.98	0	0,00	100.00
Oat	23	2.53	179	1,06	11.49
Maize (corn)	5	0.50	515	3,04	0.87
Maize (silage)	8	0.88	1,672	9,88	0.48
Mixed feed crops	9	0.99	126	0,74	6.67
Legume feed	76	8.37	206	1,22	26.95
Cultivated grassland	24	2.64	392	2,32	5.77
Pulses	24	2.64	84	0,50	22.22
Faba beans	6	0.66	11	0,06	35.29
Lupine	9	0.99	20	0,12	31.03
Peas	9	0.99	48	0,28	15.79
Potatoes (fresh)	7	0.77	109	0,64	6.03
Potatoes (industry)	1	0.08	73	0,43	0.95
Sugar beets	1	0.12	369	2,18	0.30
Feeding beets	0	0.01	4	0,02	2.44
Rape	2	0.25	1,371	8,10	0.17
Sunflowers	2	0.18	25	0,15	6.02
Soy beans	1	0.06		0,00	100.00
Flax	0	0.04	4	0,02	8.70
Medical plants	1	0.07	6	0,04	9.77
Cannabis	0	0.04		0,00	100.00
Hops	0	0.01	18	0,11	0.55
Carrots	1	0.15	10	0,06	12.30
Cabbage	0	0.03	7	0,04	3.45
Onions	0	0.04	9	0,05	3.54
Red beet	0	0.03	2	0,01	13.33
Salad	0	0.01	10	0,06	1.31
Asparagus	1	0.07	18	0,11	3.49
Strawberry	0	0.04	13	0,08	2.66
Flowers	0	0.01	34	0,20	0.36
Apples	3	0.30	32	0,19	7.83
Wine yards	4	0.48	102	0,60	4.14
Tree nursery	0	0.05	22	0,13%	2.08

Source: AMI 2010 using the basis of the test farm net data of the BMELV.

Long-term field studies on "organic versus conventional farming" confirm the advantage of organic farming to improve biodiversity for soil biota, flora, arthropods (Pfiffner, 1996; Mader et al., 2002; Entz et al., 2005; Feledyn-Szewczyk, 2008) and contribute to a better understanding of functional biodiversity (Wolfe, 2002; Zhong et al., 2005). The impact can be found on the farm land and attached areas such as hedges. Herbaceous field boundaries are rich in biodiversity and can be used as a separation between organic and conventional fields (Moonen et al., 2006; Gardarin et al., 2007). If the local biodiversity is already poor due to intensive farming in the surrounding area, organic farming can not compensate the loss of biodiversity. This was for instance shown for flower visiting insects (Hopkins and Feber, 1997; Brittain et al., 2010). Seed banks were not influenced by management (Hawes et al., 2010). It is no suitable political solution to define preference areas for organic (remote and low productive soils) and conventional farming (high potential soils) as every region should have a mixture of organic and conventional farming systems (Taube et al., 2006).

Conventional farming can have similar results in the case of compulsory set-aside farm land (segregation). Mac Donald et al. (2007) and Nemecek et al. (2006, 2011a, b) found advantages of organic farming in alpha-diversity but state that set-aside land on conventional farms can equalize this advantage. But on-farm segregation like set-aside land can be a risk for long-term biodiversity protection. As the EU set the obligation for set-aside farm land to zero in 2008, conventional farmers have converted set-aside land into crop land (Rundlof et al., 2010). This has been followed by losses of biodiversity on conventional farms.

Agri-environmental schemes (AES) have a high importance in biodiversity protection (Purtauf et al., 2005; Rund-lof et al., 2008; Taylor and Morecroft, 2009). This can be carried out as organic farming (paid under the agri-environmental schemes) or as a part of conventional farming (nature protection areas) (Schader et al., 2008). Good farming practice becomes more important to enhance and improve biodiversity in organic and conventional farming (Rydberg and Milberg, 2000; Strasser and Ryffel, 2010). Biodiversity assessment is not part of the inspection process (889/2008/EC) so that it is possible that it depends on the organic farm manager whether biodiversity will be promoted or repelled.

The main question is the antagonism between food security and biodiversity. One options to solve this problem is segregation (conventional) and integration (organic) (Gabriel et al., 2009). Differences in biodiversity have a positive and a negative impact: For example, weeds, pests and parasites dominate in organic farming (more biodiversity), are, however, negative for crop yield, product quality and animal welfare (Poetsch et al., 2005; Meyling et al., 2010). This has to be considered in the analysis of the impact of biodiversity (Letourneau and Goldstein, 2001; Letourneau and Bothwell, 2008; Ryan et al., 2010). Biodiversity needs equilibrium between biodiversity and food production (Vandana, 2000; Crowder et al., 2010; Chappell and LaValle, 2011). Biomass production is a new challenge for biodiversity protection, particularly if maize is encroaching as a monoculture (Fritsche, 2004). In addition, it should be decided, if "organic-herbicides" are a strategy (additional to mechanical and temperature weed control measures). A strong argument against such procedure is that organic farming would start to go conventional with the risk of loss of biodiversity and loss of consumer confidence (Darnhofer et al., 2010).

Hole et al. (2005) came to the conclusion, that *"(1) It remains unclear whether a 'holistic' whole-farm approach (i.e. organic) provides greater benefits to biodiversity than carefully targeted prescriptions applied to relatively small areas of cropped and/or non-cropped habitats within conventional agriculture (i.e. agri-environment schemes); (2) Many comparative studies encounter methodological problems, limiting their ability to draw quantitative conclusions; (3) Our knowledge of the impacts of organic farming in pastoral and upland agriculture is limited; (4) There remains a pressing need for longitudinal, system-level studies in order to address these issues and to fill in the gaps in our knowledge of the impacts of organic farming, before a full appraisal of its potential role in biodiversity conservation in agro-ecosystems can be made"*

The presented meta-data analysis confirms the conclusions of Hole et al. (2005). However, it is important to emphasise the fact that numerous studies favour organic farming for improving biodiversity in comparison to conventional farming. Yet, it needs to be taken into account that farming systems (including organic) and farm functions change rapidly. Energy farming and agri-environmental schemes force science to understand the impact more rapidly than in previous years. For example, biomass production can have a negative impact on biodiversity (maize domination) and biogas-facilities are installed for many decades. In future, the aspects of food security and food safety will gain increasing importance irrespective of the land use system. Putative solutions towards more biodiversity is the use of set aside farm land for segregation as it can have the same or even better impact on biodiversity than integrated measures such as organic farming. A mixture of intensive farming with set aside, non-farm land, agri-environmental schemes and organic farms may deliver a high range of biodiversity throughout all landscapes (Holland et al., 2007). A separation of these systems into specific farming areas (intensive/conventional and extensive/organic) is counter-productive.

6 Annex

Annex 1:

Comparison of Organic farming[1] (OF) and Conventional farming (CF) on biodiversity (by countries[2])

Subject	More biodiversity	Unclear, indifferent	Less biodiversity
Landscape, whole farm approach on biodiversity	BE: (Beider et al., 2007); CA: (Lynch, 2009); CH: (Schader et al., 2008; Steiner and Pohl, 2009); CR: (Blanco-Metzler and Diaz Porras, 2008); DE: (Haas and Wetterich, 2000; Holzschuh et al., 2010); DK: (Tybirk and Fredshavn, 2003; Tybirk et al., 2004); ES: (Mena et al., 2009; Jose-Maria et al., 2010); FR: (Gardarin et al., 2007); IT: (Ronchi and Nardone, 2003; Moonen et al., 2006; Lazzerini et al., 2007); SE: (Weibull, 2002; Rundlof and Smith, 2006; Rundlof et al., 2008; Rundlof et al., 2008; Rundlof et al., 2010); UK: (Norton et al., 2006; Watson et al., 2006; Gibson et al., 2007; Watson et al., 2008; Norton et al., 2009; van der Gast et al., 2011); US: (Smukler et al., 2008; Lynch, 2009; Smukler et al., 2010)	DE: (Holzschuh et al., 2007); NL: (Manhoudt and Snoo, 2003); SE: (Weibull, 2002); UK: (Hole et al., 2005; Holland et al., 2007)	
Flora on arable land	AT: (Kaar and Freyer, 2008); AU: (Macfadyen et al., 2009); CA: (Lynch, 2009); CH: (Mader et al., 2002; Nemecek et al., 2006; Hiltbrunner et al., 2008; Wyss and Pfiffner, 2008; Nemecek et al., 2011); CZ: (Tyser et al., 2008); DE: (Albrecht, 2005; Roschewitz et al., 2005a; Glemnitz et al., 2006; Himstedt and van Elsen, 2006; Clough et al., 2007a; Albrecht, 2008); DK: (Aude et al., 2003; Aude et al., 2004); ES: (Romero et al., 2005; Caballero-Lopez et al., 2010; Jose-Maria et al., 2010); EU: (Albrecht, 2003); FI: (Hyvonen et al., 2003; Ekroos et al., 2010); FR: (Bochu et al., 2004; Mesleard et al., 2005; Chateil et al., 2007); HU: (Glemnitz et al., 2006); IT: (Caporali et al., 2003; Migliorini and Vazzana, 2007; Mazzoncini et al., 2010); LT: (Balezentiene, 2008; Balezentiene, 2009); NL: (Alebeek et al., 2003; Manhoudt et al., 2007); PL: (Feledyn-Szewczyk and Duer, 2006; Feledyn-Szewczyk, 2008; Krawczyk, 2009; Krawczyk et al., 2010); SE: (Mattsson, 1999; Rydberg and Milberg, 2000; Belfrage et al., 2005; Bengtsson et al., 2005; Lundkvist et al., 2008; Rundlof et al., 2010); UK: (Cobb et al., 1999; Leake, 2002; Bartram and Perkins, 2003; Asteraki et al., 2004; Turner, 2004; Fuller et al., 2005; Hole et al., 2005; Gibson et al., 2007; Brandao et al., 2010; Hawes et al., 2010); US: (Hepperly et al., 2006; Lynch, 2009; Ryan et al., 2010; Wortman et al., 2010); ZA: (Baudron et al., 2009); No specific country: (Leifert et al., 2007; Mondelaers et al., 2009; Ulber et al., 2009)	CH: (Aavik and Liira, 2010); FI: (Hyvonen, 2007); SE: (Mattsson, 1999)	
Flora on grass land	AT: (Matthes et al., 2002; Poetsch et al., 2005); BR: (Aroeira, 2003; Aroeira and Paciullo, 2004); CH: (Schmid et al., 2001; Britschgi et al., 2006); DE: (Elsasser, 2000; Haas et al., 2001; Mayer et al., 2008; Muller-Lindenlauf et al., 2010); DK: (Petersen et al., 2006); EE: (Geherman and Viiralt, 2004); ES: (Mena et al., 2009); NL: (Baars, 2002); PT: (Crespo et al., 2004); UK: (Adamson et al., 2004; Fuller et al., 2005; Hole et al., 2005; Younie and Baars, 2005);	CA: (Brandt et al., 2010); CZ: (Sarapatka and Cizkova, 2007); EE: (Geherman and Ellermae, 2001); FR: (Benoit et al., 2005; Fiorelli et al., 2008)	
Flora on perennial crop land[3]	BR: (Batista et al., 2002); CR: (Somarriba and Harvey, 2003; Somarriba et al., 2003); DE: (Ammer et al., 1995; Geier et al., 2000); DK: (Boutin et al., 2008); ES: (Cotes et al., 2009; Minarro et al., 2009; Cotes et al., 2010); US: (Reganold et al., 2001; Nicholls et al., 2008); ZA: (Gaigher and Samways, 2010)	ES: (Minarro et al., 2009)	ES: (Minarro et al., 2009); IT: (Bruggisser et al., 2010)
Invertebrates: insects, spiders, beetles, parasites, earth worms, nematodes	AT: (Matthes et al., 2002); AU: (Macfadyen et al., 2009); AR: (Zalazar and Salvo, 2007; Fernandez et al., 2008); BG: (Andreev et al., 2001); CA: (Lynch, 2009); CH: (Pfiffner, 1996; Mader et al., 2002; Britschgi et al., 2006; Nemecek et al., 2006; Nemecek et al., 2011); CN: (Zhong et al., 2005; Chen et al., 2010; Yuan et al., 2010); DE: (Clough et al., 2005; Roschewitz et al., 2005b; Schmidt et al., 2005; Humann-Ziehank and Ganter, 2006; Clough et al., 2007a; Clough et al., 2007b; Clough et al., 2007c; Hallmann et al., 2007; Holzschuh et al., 2007; Holzschuh et al., 2008; Bates and Harris, 2009; Diekotter et al., 2010; Holzschuh et al., 2010); DK: (Boutin et al., 2009; Meyling et al., 2010); ES: (Cotes et al., 2009; Caballero-Lopez et al., 2010; Cotes et al., 2010); FR: (Garcin et al., 2004; Viaux and Rameil, 2004; Mesleard et al., 2005); FI: (Salonen et al., 2001a; Salonen et al., 2001b; Salonen et al., 2005; Ekroos et al., 2008; Ekroos et al., 2010); IN: (Suthar, 2009); IT: (Benvenuti et al., 2007; Migliorini and Vazzana, 2007; Peverieri et al., 2009; Mazzoncini et al., 2010); IR: (Hutton and Giller, 2003); NI: (Ottonetti et al., 2010); NL: (Mulder et al., 2003; Postma-Blaauw et al., 2010); NZ: (Bowie et al., 2003; Moller et al., 2007); PK: (Siddiqui et al., 2005); PT: (Santos et al., 2007); SE: (Belfrage et al., 2005; Bengtsson et al., 2005; Oberg, 2007; Rundlof et al., 2008; Rundlof et al., 2008); UK: (Cobb et al., 1999; Leake, 2002; Asteraki et al., 2004; Wickramasinghe et al., 2004; Fuller et al., 2005; Hole et al., 2005; Birkhofer et al., 2008; Eyre et al., 2009; Mondelaers et al., 2009; Hodgson et al., 2010; Eyre and Leifert, 2011); US: (Nicholls et al., 2008); ZA: (Carvalheiro et al., 2010; Gaigher and Samways, 2010); No country specified: (Boisclair and Estevez, 2006; Crowder et al., 2010)	DE: (Doring et al., 2003; Irmler, 2003; Purtauf et al., 2005); DK: (Boutin et al., 2009); FR: (Ricard et al., 2007; Pelosi et al., 2009); SE: (Weibull et al., 2000; Weibull, 2002; Weibull and Ostman, 2003); UK: (Feber et al., 1998; Feber et al., 2007; Birkhofer et al., 2008)	DE: (Clough et al., 2007a); BE: (Albert et al., 2003); IT: (Boisclair and Estevez, 2006; Bruggisser et al., 2010); FR: (Garcin et al., 2004); SE: (Oberg, 2007; Oberg, 2009)

Subject	More biodiversity	Unclear, indifferent	Less biodiversity
Birds, mammals, aquatic fauna	DE: (Batary et al., 2010); CA: (Freemark and Kirk, 2001; Bugg, 2002); IT: (Ciani, 1997; Genghini et al., 2006); FR: (Mesleard et al., 2005; Ondine et al., 2009); PA: (Bael et al., 2007); NL: (Kragten and de Snoo, 2007; Kragten and de Snoo, 2008); SE: (Belfrage et al., 2005; Bengtsson et al., 2005; Danhardt et al., 2010; Smith et al., 2010); UK: (McLaughlin and Mineau, 1995; Bugg, 2002; Leake, 2002; Potts, 2002; Wickramasinghe et al., 2003; Wickramasinghe et al., 2004; Fuller et al., 2005; Hole et al., 2005; McKenzie and Whittingham, 2009; Mondelaers et al., 2009; Chamberlain et al., 2010); US: (Bugg, 2002)	NL: (Kragten and de Snoo, 2007; Kragten and de Snoo, 2008); FR: (Ondine et al., 2009); SE: (Danhardt et al., 2010); UK: (Chamberlain et al., 2010)	
bacteria, yeast, pests	AU: (Bissett et al., 2006; Bissett et al., 2007; Macfadyen et al., 2009); ES: (Escudero et al., 2007; Cordero-Bueso et al., 2011); US: (Letourneau and Goldstein, 2001; Letourneau and Bothwell, 2008)	BE:(Coorevits et al., 2008); US: (Letourneau and Bothwell, 2008)	FR: (Benoit et al., 2005)
Soil biota	AU: (Bruggen and Termorshuizen, 2003; Bell et al., 2004); BR: (Lal, 2005); CH: (Fliessbach et al., 2000; Mader et al., 2002; Oehl et al., 2004; Nemecek et al., 2006; Oehl et al., 2009; Nemecek et al., 2011); DE: (Poveda et al., 2006; Diekotter et al., 2010); CL: (Peredo et al., 2009); DK: (Hansen et al., 2001); FR: (Peres et al., 2008); GR: (Tsiafouli et al., 2006); HR: (Custovic and Tvica, 2004); IN: (Tilak et al., 2005); IT: (Cardelli et al., 2004; Migliorini and Vazzana, 2007; Mocali and Benedetti, 2008; Campaneili et al., 2010; Mazzoncini et al., 2010; Paoletti et al., 2010); JP: (Nakamura et al., 2000); NL: (Mulder et al., 2003; Breure et al., 2004; van Diepeningen et al., 2006; Verbruggen et al., 2010); PK: (Rana et al., 2010); UK: (Leake, 2002; Shannon et al., 2002; Mondelaers et al., 2009; Stockdale and Watson, 2009; van der Gast et al., 2011); US: (Wander et al., 1995; Tu et al., 2006; Reeve et al., 2010); No country specified: (Creamer et al., 2010)	CL: (Peredo et al., 2009); DE: (Schrader et al., 2006; Chirinda et al., 2008); FR: (Peres et al., 2008; Pelosi et al., 2009); IT: (Bedini et al., 2008; Paoletti et al., 2010); NL: (Zanen et al., 2008; Galvan et al., 2009); NZ: (Parfitt et al., 2005); UK: (Shannon et al., 2002; Brussaard et al., 2004; Orr et al., 2011); US: (Bossio et al., 1998; Sanchez-Moreno et al., 2008)	
Agro-biodiversity	AT: (Vogl and Vogl-Lukasser, 2003); CA: (Scott, 2000; Lynch, 2009); CH: (Freyer, 1997); DE: (Muller et al., 2000; Wolff et al., 2002; Buchs, 2006); EU: (Bocci and Chable, 2009); ES: (Correal et al., 2006; Mena et al., 2009; Cordero-Bueso et al., 2011); FR: (Tronel and Codarin, 2010); HU: (Birol et al., 2005; Birol et al., 2006); IT: (Ronchi and Nardone, 2003); IN: (Vijayalakshmi and Arumugasamy, 2004); HR: (Lotti et al., 2008; Matotan et al., 2008); NL: (Bueren and Osman, 2001; Bueren et al., 2002); SE: (Rydberg and Milberg, 2000); UK: (Leake, 2002; Hole et al., 2005; Gibson et al., 2007; McKenzie and Whittingham, 2009; Mondelaers et al., 2009); US: (Lynch, 2009); No specific country: (Shiva, 1997)	DE: (Langer and Frederiksen, 2008)	
General and not species-specified comments concerning organic farming and biodiversity, farm assessments	AT: (Loidl, 2007); BE: (Baltus, 1997); BH: (Aziz and Al-Barakah, 2005); BR: (Alvarenga et al., 2002); CH: (Fliessbach et al., 2000; Wolfe, 2002; Nemecek et al., 2006; Strasser and Ryffel, 2010; Nemecek et al., 2011); CN: (Wang et al., 2007; Wang et al., 2009); CR: (Somarriba and Harvey, 2003; Somarriba et al., 2003; Dahlquist et al., 2007); DE: (Ammer et al., 1995; Elsen, 2000; Stein-Bachinger et al., 2005; Gabriel et al., 2006; Gabriel and Tscharntke, 2007; Stein-Bachinger and Fuchs, 2008; Gabriel et al., 2009; Gabriel et al., 2010; Muller-Lindenlauf et al., 2010); DK: (Porter and Petersen, 1997; Noe et al., 2005; Vaarst, 2010); ES: (Calero Castillo, 2003; Parra-Lopez et al., 2007); EU: (Bandarra, 2001); FR: (Chable et al., 2002; Dron and Ferron, 2003; Lamine and Bellon, 2009); GE: (Adl et al., 2006); HU: (Toth and Baldi, 2006); IN: (Ayyappan and Jena, 2003; Singh, 2005a; Singh, 2005b; Singh et al., 2007; Singh and Satapathy, 2007; Dubey and Sharma, 2008; Subhasis et al., 2008); IT: (Pacini et al., 2003; Ronchi and Nardone, 2003; Migliorini and Vazzana, 2007); MX: (Bray et al., 2002; Escamilla et al., 2005); NL: (Smis and Meijerink, 2006); NO: (Olsson and Rnningen, 1999); PO: (Link, 2004); UK: (McLaughlin and Mineau, 1995; Cobb et al., 1999; Atkinson et al., 2002; Dabrowski and Abanowska-Bury, 2005; Firth et al., 2006; Norton, et al. 2006; Watson et al., 2006; Watson et al., 2008; Norton et al., 2009; Taylor and Morecroft, 2009); US: (Altieri, 1999; Lotter, 2003; Snapp et al., 2010; Chappell and LaValle, 2011); No specific country: (Mansvelt and Lubbe, 1999; Leake, 2002; Scialabba et al., 2003; Xie et al., 2003; Kairo, 2005; Pimentel et al., 2005; Leifert et al., 2007; Briggs, 2008; Schnug et al., 2008)	AT: (Darnhofer et al., 2010); MX: (Philpott et al., 2007); NL: (Bueren and Osman, 2001; Ammann, 2007; Ammann, 2008; Ammann, 2009)	US: (Avery, 1996); SE: (Kirchmann and Thorvaldsson, 2000); NZ: (Rowarth, 2008)

343 papers were assessed. Multiple citations are possible due to different conclusions for different species.
[1] This includes organic farming, wild plant collection, traditional farming under organic standards (without certification).
[2] ISO country codes are used.
[3] Perennial crop land: e.g., agro-forestry, orchards, vineyards.
Source: web of science search using Endnote® in March 2011)

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Improving green-house gas balances of organic farms by the use of straight vegetable oil from mixed cropping as farm own fuel and its competition to food production

Hans Marten Paulsen*

Abstract

Mixed cropping is frequently used in organic farming and recommended worldwide in low external input areas to increase productivity, yield security and product diversity. In trials with different oil crops camelina (false flax, *Camelina sativa L.*), linseed (*Linum ustitatissivum L.*), rape (*Brassica napus L.*), safflower (*Carthamus tinctorius L.*) or white mustard (*Sinapis alba L.*) grown together with grain legumes or cereals on German sites the potential of renewable fuel production parallel to food production was evaluated in organic farming. Depending on the crop-combination between 10 to 900 kg/ha vegetable oil could be produced. This could cover the fuel demand of agricultural machinery for 0.1 to 9 ha farmland. The food crops combined with oil plants in mixed cropping mostly had relative yields higher as 0.5, showing that also yield increases in food production are possible parallel to the production of renewable fuel. As example for an introduction of a non-common oil crop in farm cycles, research results on the use of straight vegetable oil as fuel in tractors and of oil-cake as feedstuff for livestock from camelina are summarised. Based on the results the importance for the GHG emissions of organic farms is discussed. When mixed cropping systems with oil crops and the use of all products are consequently introduced, improvements in the GHG balance of farms can be expected by savings in production and yield stabilisation in mixed cropping as well as by direct substitution of diesel fuel in agricultural machinery and by substitution of imported feed components for livestock.

Keywords: Organic farming, feed components, food and biofuel, mixed cropping

Zusammenfassung

Verbesserung der Treibhausgasbilanzen ökologischer Betriebe durch die Nutzung von Pflanzenöl aus dem Mischfruchtanbau als hofeigenen Biokraftstoff und die Konkurrenz zur Nahrungsmittelproduktion

Mischfruchtanbau wird im Ökologischen Landbau und auch weltweit in Anbauregionen mit schlechtem Zugang zu externen Betriebsmitteln angewandt, um die Produktivität, Ertragssicherheit und die Produktionsvielfalt abzusichern und zu steigern. In Versuchen mit verschiedenen Ölfrüchten Leindotter *(Camelina sativa L.*), Öllein (*Linum ustitatissivum L.*), Raps (*Brassica napus L.*), Saflor (Färberdistel, *Carthamus tinctorius L.*) *oder* weißem Senf (*Sinapis alba L.*) im Mischfruchtanbau mit Körnerleguminosen oder Getreide in Deutschland wurde das Potential dieser Anbausysteme zur Biokraftstofferzeugung parallel zur Nahrungsmittelproduktion ermittelt. Abhängig von der Fruchtartenkombination konnten im Ökologischen Landbau so 10 bis 900 kg/ha Pflanzenöl erzeugt werden. Dies könnte den Treibstoffbedarf für die Bewirtschaftung von 0,1 bis 9 ha Land abdecken. Für die gleichzeitig produzierten Nahrungs- bzw. Futterpflanzen wurden überwiegend Relativerträge von größer als 0,5 ermittelt. Der Wert zeigt, dass neben der Erzeugung von Pflanzenöl, z. B. zur Nutzung als Biotreibstoff, auch Ertragssteigerungen bei den Nahrungspflanzen erzielt werden können. Als Beispiel für die Einführung einer Ölfrucht in den Kreislauf landwirtschaftlicher Betriebe werden Forschungsergebnisse zum Einsatz von reinem Pflanzenöl als Biotreibstoff in Traktoren und zur Nutzung des Ölkuchens von Leindotter in der Nutztierfütterung beschrieben und deren Bedeutung für die Treibhausgas(THG)bilanz landwirtschaftlicher Betriebe dargestellt. Bei Einführung von Mischfruchtanbausystemen mit Ölpflanzen und der konsequenten Nutzung aller erzeugten Komponenten im Betrieb können THG-Emissionsminderungen in der landwirtschaftlichen Produktion, durch die Ertragsstabilisierung durch den Mischfruchtanbau sowie durch die direkte Substitution von Dieselkraftstoff in landwirtschaftlichen Fahrzeugen und von sonst importierten Futterkomponenten für die Nutztiere erzielt werden.

Schlüsselworte: Ökologischer Landbau, Futterkomponenten, Nahrung und Biokraftstoff, Mischfruchtanbau

* Johann Heinrich von Thünen Institute (vTI), Federal Research Institute for Rural Areas, Forestry and Fisheries, Institute of Organic Farming, Trenthorst 32, 23847 Westerau, Germany, hans.paulsen@vti.bund.de

1. Introduction

Mixed cropping is a management tool that is used in organic farming in terms of efficient resource use and risk minimization (Jensen, 2006; Hof and Rauber, 2003). A very special production line is mixed cropping with oil crops (Paulsen, 2007a and 2008a; Carr et al., 2003; Szumigalski and van Acker, 2005 and 2006). Due to very insecure yields of oil crops in organic farms mixed cropping could be used to secure oilseed production at all if suitable companion crops are found. Special yield goals of this cropping type could be defined for co-production of food and renewable energy.

As straight vegetable oil can be directly used as fuel for farm machinery (Ramadhas, 2004; Hassel and Wichmann, 2005) oil crop yield from mixed cropping must be adapted to the fuel demand of the farm and feed crops could be produced parallel (Paulsen, 2008b; Paulsen and Rahmann, 2004).

GHG loads of organically produced vegetable oil can be very low due to the low external energy input in organic production (Cormack, 2000). Oil crops cultivated in mixed cropping systems have additional energy demands for technical equipment for seeding and separating the seeds after harvest. Furthermore probable yield reduction of the main crop would cause loads for the oil crop e. g. in GHG balances. But also positive yield effects of companion oil crops are reported. This would have reducing effects on the GHG emission of whole production as well as the use of renewable energy. Additionally oil cake from oil production can replace other imported feed components with indifferent climate loads (Steinfeld, 2006).

Mixed cropping for energy production would probably be needed in various elements of a crop rotation to supply sufficient fuel in organic farming. This implies a need for the use of vegetable oil from different oil crops in the machines and for the use of different oil-cakes in animal feeding.

In the following recent own research results on yield of mixed cropping systems with different oil crops in organic production, results on the use of camelina oil as fuel component in agricultural machinery and on oil cake in chicken feeding are summarized. Based on these results the effects of the introduction of these measures on the green house gas (GHG) load of production are discussed.

2. Materials and Methods

Field trials

Field trials of mixed cropping with oil crops were undertaken at four sites in Germany with the oil crops camelina (false flax, *Camelina sativa L.*), linseed (*Linum ustitatissivum L.*), rape (*Brassica napus L.*), safflower (*Carthamus tinctorius L.*) and white mustard (*Sinapis alba L.*). The oil crops were sown in completely randomized block designs with four repetitions together with different legumes (pea - *Pisum sativum L.* or blue lupin - *Lupinus angustifolius L.*) or cereals (wheat - *Triticum aestivum L.*, barley - *Hordeum vulgare L.* or rye - *Serale cereale L.*). In mixtures with winter rape winter varieties were used as cropping companions (Table 1). Also the mixed cropping of two oil crops – linseed together with camelina – was tested. In the following text the introduced oil crops are further called 'oil crops'. The other crops in the mixture are called 'main crops'. Both crops were sown in separate rows and optimal depths each. The seed row distances were kept constant in sole and mixed cropping (12 to 12.5 cm). Consequently most seed rates of oil crops and main crops were reduced to 75 % or 50 % compared to the sole cropping, according to existing field experiences. The trial design is given in Paulsen (2007b). Yield effects compared to sole cropping therefore could be expected by plant reduction per area, by different intrarow plant distances as well as by interrow plant competition of different varieties. After harvest the seeds were divided and weighed separately. Additionally all crops were grown in pure stand to calculate the Land Equivalent Ratio (LER) (Mead and Willey, 1980).

Feeding trials with oil cakes

Camelina oil cake was taken as example for a novel crop with special fatty acid composition and its usability in diets for broiler fattening. Camelina oil cake as ingredient was critically discussed in terms of negative influences on fat odour and taste when used in pig or broiler nutrition (Böhme and Flachowsky, 2005). Since 2008 it is accepted in the EU feed law (Commission directive 2008/76/EC). In a feeding trial on chicken fattening energy equal feed rations with 0, 2.5 or 5 % camelina oil cake were used. Chicken were slaughtered, parameters of fattening performance, carcass quality, organ weights and sensoric meat quality were determined (Weissmann et al., 2007).

Tests in straight vegetable oil driven tractors

Usability of mixed straight vegetable oils as fuels was exemplarily examined in agricultural tractors with engines adapted to the use of straight rape oil. Two modern common rail tractors with 150 kW were compared over 1000 h in one year in a field test. One tractor was driven with cold pressed rape oil and one with a mixture of 30 % camelina oil and 70 % rape oil. Fuel qualities were examined according to DIN V 51605 (2006). Motor oil samples were controlled on vegetable oil content, viscosity and carbon residues.

Estimation of GHG loads

The potential of GHG reduction on farms by the substitution of diesel fuel by straight vegetable oil was calculated with an emission factor of 83.3 g CO_2eq/MJ diesel and an energy content of diesel of 43 MJ/kg or 36 MJ/l (EU, 2009).

3. Results and Conclusions

Yield potential of mixed cropping with oil crops

Mixed cropping is seen as measure to ease overall yields, due to different growing habits and resource demand of the different plants (Trentbarth, 1986). Due to this and to special site conditions also in the reported trials a very large bandwidth of yield combinations was obtained. Reasons for the yield variation were low field establishment of spring seeds due to spring drought periods (obvious in low yield levels of the main crop in sole cropping), problems with seeding technology of fine seeds and insect pests (*Melingetes anuus*) on nearly all sites and years in all cruciferous plants which is typical for organic farming conditions (Petterson et al., 2002; Valantin-Morison and Meynard, 2007 and 2008). In Table 1 the average yields over all sites and years are given. The results are given in detail by Paulsen and Schochow (2007).

Table 1:

Average grain yields of mixed and sole cropping systems of various main crops and oil crops in organic farms [kg/ha dry matter] and land equivalent ratio of mixed cropping (LER) (4 German sites in 2004 and 2005)

	oil crops		main crops		mixed cropping	LER
crop combination	sole	mixed	sole	mixed	total	
winter varieties:						
barley/rape	720	250	3580 a	1910	2160 b	0.88
rye/rape	610	230	4490 a	2630	2750[b]	0.96
pea/rape	720	490	320 b	370	870 a	1.84
spring varieties:						
pea/camelina	1100	750	1470 b	1120	1870 a	1.44
pea/camelina[l]	1260	470	2480 b	2350	2830 a	1.32
pea/rape	40	40	1470 b	1760	1800 a	2.20
pea/w. mustard	630	450	1470 a	700	1150 b	1.19
lupin/camelina	1100	750	1410 b	910	1660 a	1.33
lupin/safflower	1080	800	1410 a	470	1270 a	1.07
wheat/camelina	1100	370	3660 a	2660	3030 b	1.06
wheat/linseed	740	140	3660 a	2990	3140 b	1.01
camelina[m]/linseed	740	240	1100 a	890	1140 a	1.13

[l] camelina in broadcast seeding, [m] main crop camelina
a,b: significant differences between yields of main crops are indicated by different letters ($p < 0.05$)

Mixed cropping of legumes with rape or camelina on average lead to a remarkable total yield increase compared to the sole cropped main crop. High LER values between 1.32 and 2.20 indicate the high area efficiency of production of those mixtures (Table 1).

Camelina delivered on average between 370 and 750 kg/ha seeds with a moderate yield reduction of the main crops (pea or blue lupin). LER values between 1.32 and 1.44 were reached. Maximum yields of 1.75 t and 2.36 t ha camelina occurred in pea or *L. angustifolius*, respectively. At this yield level the yields of the main crops were strictly reduced (Paulsen, 2007a). Pea (winter variety) was kept upright by the rape (winter variety) and reached higher yield in mixed cropping. But both cultures were at an unsatisfactory low yield level. Flowers and seeds of rape (spring variety) were almost destroyed completely by insects in mixed and sole cropping. This and an average yield increase of pea in mixed cropping with rape (spring variety) lead to the high LER value of 2.2. Due to their described extreme yield risk mixtures with rape need further evaluation.

Safflower proofed to be very competitive in mixture with *L. angustifiolius*. At an LER of 1.07 of mixed cropping the yield was dominated by safflower (Table 1). This tendency was additionally increased by the differing ripening times of both cultures which lead to pre-harvest yield losses in blue lupin. Further camelina or linseed were dominated by spring wheat in mixed cropping. Spring wheat realized disproportionately high yields in mixed cropping if plant number reduction and extension in row distances in relation to sole cropping which were given by the trial design are considered. In those systems the oil crops camelina or linseed showed seed yields of 370 kg/ha and 140 kg/ha (dry matter), respectively. Maximum yields of camelina of 960 kg/ha (dry matter) only occurred together with low yield levels of the main crop spring wheat (Paulsen, 2007b). In mixed cropping with linseed, camelina dominated the yield. But also in the four latter mixed cropping systems LER values larger than one could be reached (Table 1). Except the mixtures pea/white mustard and lupin/safflower in all mixed crops the main crops had relative yields higher as 0.5. This means that yield increases in food production are possible parallel to the production of renewable fuel.

Mean absolute yield gains and losses of mixed cropping with oil crops in organic farms at same area use both cultures would have in sole cropping are tabulated in Table 2. This scenario can be helpful, when oilseeds shall be produced in the farm and mixed cropping shall help to overcome cropping difficulties e. g. in weed or pest management (Saucke and Ackermann, 2006; Paulsen et al., 2006; Paulsen et al., 2007b). Therefore in Table 2 the introduction of 2 ha mixed cropping is compared with the production of 1 ha of each culture in sole cropping.

Except for combinations of pea with white mustard and of blue lupin with safflower all combinations lead to an improvement of the absolute seed production of the main crop on farm level. Oil crops were produced in all systems. A decrease in oil crop production on farm level compared to sole cropping systems was obvious in combinations of oil crops with wheat, when camelina was grown in broadcast seeding together with peas, in most combinations with rape and finally in linseed if combined with camelina (Table 2).

Table 2:

Yields and yield gains or losses by mixed cropping compared to sole cropping at equal land use [kg/ha dry matter]

	farm yield 2 ha				additional	
	mixed cropping		sole cropping		farm yield by mixed cropping	
	/ 2 ha		/1 ha	/1 ha	/1 ha	
crop combination	oil crop	main crop	oil crop	main crop	oil crop	main crop
winter varieties:						
barley/rape	500	3820	720	3580	-110	+120
rye/rape	460	5260	610	4490	-75	+385
pea/rape	980	740	720	320	+130	+210
spring varieties:						
pea/camelina	1500	2240	1100	1470	+200	+385
pea/camelina[l]	940	4700	1260	2480	-160	+1110
pea/rape	80	3520	40	1470	+20	+1025
pea/w. mustard	900	1400	630	1470	+135	-35
lupin/camelina	1500	1820	1100	1410	+200	+205
lupin/safflower	1600	940	1080	1410	+260	-235
wheat/camelina	740	5320	1100	3660	-180	+830
wheat/linseed	280	5980	740	3660	-230	+1160
camelina[m]/linseed	480	1780	740	1100	-130	+340

[l] camelina in broadcast seeding, [m] main crop camelina

But an overall yield gain (oil crops + main crops) in all mixed cropping systems is obvious. The decision which cropping system is preferred therefore is dependant of yield risk assessments of sole cropping and of positive aspects mixed cropping may deliver (physical stabilisation aspects, weed suppression, yield buffering aspects). Also goals for seed yields will influence the choice of the cropping system.

Organic mixed cropping systems with camelina proofed to be relatively robust in yields and ripening times over the years and showed yield buffering capacities. Therefore further studies on the use of its oil and oil cake on farms were undertaken. These experiences are described in the following. The possible effects on changes of GHG balances on farm level after introduction of the system are estimated.

Use of oil cakes in livestock feeding and alternative usages

In organic livestock nutrition the use and production of a sufficient amount of high-quality feed components containing protein and amino acids is essential for the creation of pure on farm diets (Zollitsch et al., 2004). The use of locally produced oil cakes would help to avoid external environmental effects and GHG loads by import of feed components (Steinfeld et al., 2006). Replacement of oilcake from soya (*Glycine max)* which might be polluted with GMO from conventional production (Partridge and Murphy, 2004) would be another important aspect to guarantee food security in organic farms.

In terms of its gucosinolate contents and its content of linolen- and linolenic acid the use of camelina oil cake in animal nutrition was critically discussed (Böhme and Flachowsky, 2005). Further trials on an adequate dosage in poultry production were undertaken (Jaskiewicz and Matyka, 2003; Weissmann et al., 2007). Today there is a general allowance of the ingredient in livestock feeding (Commission directive 2008/76/EC).

Table 3:

Effects of the complete replacement of oil cake of soya (5 %-content) by oilcake of camelina in feeding ratios for chickens on performance and meat quality (Weissmann et al., 2007)

	G. max oil cake	Camelina oil cake
Fattening performance, n=	44	48
Slaughtering weight, g	3741 b	3883 ab
Daily weight gain, g	44.0 a	45.8 a
Feed intake, g/d	100.7 bc	107.6 ab
Feed conversion, g/g	2.38	2.35
Organ weights, n=12		
Thyroid, g	0.341 b	0.351 b
Liver, g	70.8 ab	74.3 ab
Carcass yield, %	69.4 ab	69.5 ab
Sensoric meat quality (leg) (1= bad, 6=very good)		
Tenderness	4.3	4.2
Juiciness	4.3	4.5
Aroma	4.1	3.9
Fatty acid composition of intramuscular fat		
SFA[1], %	28.2 a	28.0 a
MUFA[2], %	38.5	40.5
PUFA[3], %	33.1	31.3
Rest, %	0.2	0.2

a, b, c: different letters indicate significant differences ($p \leq 0,05$),
[1] Saturated Fatty Acids: C14:0 , C16:0, C18:0; [2] Mono Unsaturated Fatty Acids: C16:1, C18:1, C20:1, C22:1; [3] Poly Unsaturated Fatty Acids: C18:2, C18:3, C20:4

Results on the successful complete replacement of soya oil cake by camelina oil cake in organic chicken feed ratios are presented in Table 3, exemplarily. Animal performance and meat quality in the chicken fattening were not influenced (Weissmann et al., 2007).

The consequences for the reduction of GHG of organic production which might be caused by this replacement is unclear but would surely be high if land use changes for e. g. organic production of soya can be avoided (Weightman et al., 2010).

Alternative usages of the oil cakes are seen in organic fertilisation (Laber, 2003) and in the use as additional substrate in biogas plants (Paulsen et al., 2009). In general usages like this might cause additional mitigation effects on GHG emissions of farms by substitution of other fertilisers, by a yield increase through fertilisation or by the substitution of other biogas co-substrates and the increase of the amount of renewable energy that is produced.

Tests in straight vegetable oil driven tractors

Tractors which were technically adapted to the use of straight vegetable oil as pure fuel are on the market or can be constructed by special suppliers. Several studies on the use of vegetable oil in diesel engines are available (Ramadhas, 2004; Knothe et al., 1991) and were updated in practical field studies with modern agricultural machinery that was adapted to the use of rape oil according to the DIN V 51605 in Germany (Hassel and Wichmann, 2005) and Austria. Research on possibilities to fulfill the coming exhaust regulations and on the newest technical development is running in an EU-wide demonstration project (http://www.2nvegoil.eu/default.asp?Menue=93). Further technical development concentrates on the purification of cold pressed and refined vegetable oils to exclude unwanted P, Ca, Mg contents (Remmele, 2002; http://www.faqs.org/patents/app/20100024284).

For the demands of organic farming and of the mixed cropping approach a variety of oil crops is needed to be used in engines. The results of the exemplary field tests on the replacement of 30 % rape oil by camelina oil and the use as mixed fuel can be summarized as follows:

The tractor was driven without complications over 1000 h under different loads. The motor oil quality was always suitable and wide below critical thresholds (vegetable oil content, carbon particles, viscosity) also after the maximum period between the oil change of 350 h that was used.

Oxidation resistance of the straight vegetable fuel mixture was always under the DIN norm given for rape oil when used as fuel (Table 4).

Table 4:

Parameters of fuel characteristics of a 70 %/30 % mixture of rape oil and camelina oil

Parameter	Unit	Threshold DIN V 51605**	Oil mixture
CCR*	%(m/m)	≤ 0.40	0.46
Iodine number	g/100g	95 - 125	125
Acid value	mg KOH/g	≤ 2.0	1.59
Oxidation stability	h	≥ 6.0	4.0
P-content	mg/kg	≤ 12	11
S-content	mg/kg	≤ 10	3
Σ Ca + Mg	mg/kg	≤ 20	20.9

* Conradson Carbon Residue, **parameter CCR not any longer listed in the final DIN 5160 and new thresholds for P: 3 mg/kg, Ca: 1 mg/kg, Mg: 1 mg/kg valid in 2012

After 1000 h carbonaceous deposits at the fuel injectors were detected. But it remained unclear if they were caused by the use of cold pressed oils which in general are of lower pureness than raffinates or by the use of the oil mixture itself because Ca and Mg contents of straight camelina oil was nearly in range with that of the rape oil that was used. Anyway the CCR values of the oil-mixture exceeded the threshold given in the DIN V 51505 (Table 4). The tractor had the same power and showed no difference in emission of NO_x, CO, HC and particles compared to the use of straight rape oil. Principally the use of 30 %/70 % camelina/rape oil as fuel in diesel engines that are adapted to the use of straight vegetable oil is possible. In general increased attention on motor control (injectors, motor oil quality) must be taken when cold pressed and unrefined vegetable oil is used. But the use of vegetable oil beyond the DIN norm cannot be recommended if warranty aspects of the engines are considered.

But market studies on the practical trading of vegetable oils showed that different vegetable oils are mixed as fuel and are sold as vegetable oil according to DIN V 51605 (Paulsen et al., 2007a). Vegetable oil mixtures for the use as fuel are obviously market conform and can therefore be part of considerations on the replacement of fossil fuels.

Estimation of GHG loads

The additive potential of the mixed cropping system, the use of the vegetable oils as fuels in agricultural machinery and the use of oil cake as feed component to reduce the emission of CO_2-equivalents per hectare must be calculated based on the allocation of emission factors for the substituted materials (fossil fuel and other feed components) and by the hectare wise yield effects of the mixed cropping systems. Values on these overall effects of mixed cropping for the described mean yield levels (Table 1) are given in Table 5.

Table 5:

Gains (+) and losses (-) in grain yields (dry matter) of various main crops in organic farms (a), additional oil (b) and oil cake yields (c) and change in produced raw protein (XP) (d) and energy production (e) when mixed cropping with oil crops is introduced (yields: see Table 1 and 2) and the reduction of GHG emissions by the substitution of diesel fuel by the produced straight vegetable oil (f)

	(a)	(b)	(c)	(d)	(e)	(f)
crop combination*	+/-	+	+	+/-	+/-	-
	main crops	veg. oil	oil-cake	XP [b]	heating value	CO_{2eq}
	kg/ha				[c]MWh/ha	[d]kg/ha
winter varieties:						
barley/rape	-1670	100	150	-105	-6.3	-313
rye/rape	-1860	92	138	-95	-7.3	-288
pea/rape	+50	196	294	+126	+3.7	-614
spring varieties:						
pea/camelina	-350	285	465	+116	+3.6	-893
pea/camelina[l]	-130	179	291	+118	+2.7	-561
pea/rape	+290	16	24	+6	+1.7	-50
pea/w. mustard	-770	113	338	-26	-0.5	-354
lupin/camelina	-500	285	465	+11	+2.9	-893
lupin/safflower	-940	160	640	-229	+1.1	-502
wheat/camelina	-1000	141	229	-16	-2.2	-442
wheat/linseed	-670	53	87	-55	-2.2	-166
camelina[m]/linseed	-210	91	149	+17	+0.7	-285

[l] camelina in broadcast seeding, [m] main crop camelina, [b] effects of mixed cropping on grain N contents are considered, XP=N*6.25, [c] oil crops 7 kWh/kg dry matter, cereals/legumes 4.8 kWh/kg dry matter, [d] 3603.4 gCO_{2eq}/kg diesel = 83.8 gCO_2eq/MJ (EU 2009)

On the contrary to the interpretation given in connection with Table 2 the values in Table 5 have to be interpreted with the background that mixed cropping is introduced in a farm to combine feed and fuel production in one field. So the pure yield effect per hectare is given here and not the effect on farm level.

Under this assumptions in the most cropping systems the kernel yield of the main crop per hectare is reduced, exceptional are pea (winter variety) yields in combination with rape (winter variety) and pea in combination with rape (spring variety) (Table 5, column a). This was also found in other studies on combinations of rape with cereals (Szumigalski and van Acker, 2005), wheat and linseed (Carr et a., 1993), safflower in combination with seed legumes, rape or turnip rape *(Brassica campestris L.)* (Rafey and Prasad, 1991) and beans *(Vicia faba L.)* in combination with safflower or linseed (Kiessling, 2011). But also yield increases respectively yield constancy of peas in mixed cropping with false flax compared to sole cropped peas can occur (Saucke and Ackermann, 2006). But inherent to the system all mixed cropping systems delivered additional vegetable oil and oil cake per hectare (Table 5, columns b and c). Considering the total produced raw protein of the different crop combinations (Table 5, column d) it is obvious that if the yield reductions are moderate and the oil yields are relatively high additional protein can be produced. This protein can replace necessary feed protein imports and replace their GHG loads directly or can increase the yield of livestock production by high quality farm own feed components. This can decrease the product related GHG emissions.

The heating value of the whole seed production of mixed cropping compared to the sole cropped main crops is given as integrating value for overall energy production of the systems (Table 5, column e). The combinations delivering higher protein yields and also the combination of blue lupin with safflower show an energy win per hectare compared to the sole cropping of main crops. In the latter combination high yield losses in blue lupin occurred and the raw protein losses on this side couldn't be compensated by safflower, whereas the energetic approach delivered an increase in energy per hectare due to the assumed heating value of the oil crop.

By the direct replacement of fossil fuel with vegetable oil from mixed cropping between 50 and 893 kg/ha CO_2-equivalents could be replaced (Table 5, column f). Assuming a fuel demand for agricultural machinery of 100 kg/ha farmland average straight vegetable oil yields from 1 ha could make up to 3 ha self reliant in fuel. With the maximum values of oil production in mixed cropping with camelina reported before fuel self-reliance for up to 9 hectare could be reached with 1 ha farmland.

Further considerations of the effects of mixed cropping systems with oil crops have to consider the possible additional energy demand for their introduction. It can be minimized e. g. by the combination of seeding technology (Paulsen und Pscheidl, 2007). Additional factor demands of mixed cropping arise in the seed production and in the seed separation after harvest. But these points are seen to be of minor importance in life cycle balances (Sergis-Christian und Browers, 2005) and must be compensated by the advantages of the cropping systems described before. In general mixed cropping with oil crops in organic farming is seen as highly specialised opportunity to produce oil crops (Gruber and Vogt-Kaute, 2007) which has clearly to be adapted to site conditions.

Conclusions

Mixed cropping with oil crops can enable organic farmers to introduce oil crops in their crop rotation. Looking from this direction mixed cropping on one field compared to sole cropping of main and oil crops on different fields lead to increased farm production of both products. This alone can mean clear reducing effects on the product related GHG emission of organic agricultural production.

Mixed cropping with oil crops can also be introduced as cropping concept to produce straight vegetable oil as fuel for agricultural machinery. Yields of the main crops will be reduced in that case but are replaced by products with other quantities and qualities. This has to be considered in farm balances and in their scenario descriptions.

With straight vegetable oil from mixed cropping with oil crops fossil fuel can be replaced. The co-product oil cake and an increased protein production per hectare mean an added value for livestock productivity and a reduction of imported feed components can be expected. These aspects offer clear potential of the described system to reduce GHG emissions of organic farms. The production of biofuel in this way has only moderate competition to food production.

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Update of the calculation of metabolizable energy requirements for pigs in the German agricultural emission inventory

Hans-Dieter Haenel*, Ulrich Dämmgen*, Petra Laubach**, and Claus Rösemann*

Abstract

The calculation of the energy requirements of pigs used in the German agricultural emission inventory is updated on the basis of the recommendations worked out by the German Society of Nutrition Physiology (GfE). At the same time the numeric solutions hitherto used in the calculations of energy requirements of weaners and fattening pigs in the emission inventories are replaced by analytical solutions. This results in simplifications in the calculation procedures.

In the inventory this leads to reduced energy requirements for fattening pigs. However, the energy requirements for sows, weaners and boars increase.

Keywords: pigs, energy requirements, model, emission inventory

Zusammenfassung

Aktualisierung der Berechnung des Bedarfs an umsetzbarer Energie von Schweinen im deutschen landwirtschaftlichen Emissionsinventar

Die Berechnung des Bedarfs an umsetzbarer Energie für Schweine im deutschen landwirtschaftlichen Emissionsinventar wird aktualisiert. Grundlage sind die vom Ausschuss für Bedarfsnormen der Gesellschaft für Ernährungsphysiologie (GfE) erarbeiteten Richtwerte. Gleichzeitig werden die bisher im Emissionsinventar üblichen numerischen Lösungen der Berechnungen des Energiebedarfs für Aufzuchtferkel und Mastschweine durch analytische Lösungen ersetzt und damit die Rechenverfahren vereinfacht.

Im Inventar ergeben sich daraus für Mastschweine eine Verringerung des Energiebedarfs, für Sauen, Aufzuchtferkel und Zuchteber jedoch Erhöhungen.

Schlüsselwörter: Schweine, Energiebedarf, Modell, Emissionsinventar

* Johann Heinrich von Thünen Institute (vTI), Institute for Agricultural Climate Research, Bundesallee 50, 38116 Braunschweig, Germany

** Association for Technology and Structures in Agriculture (KTBL e.V.), Bartningstr. 49, 64289 Darmstadt, Germany

1 Introduction

Agricultural production involves the emission of trace gases whose effects on the atmosphere and the environment may be adverse. Attempts to reduce these emissions presuppose their detailed quantification in a way that allows for the identification and evaluation of the relevant processes. As emission reduction goals are being discussed in international boards, the respective parties use standard approaches to describe and quantify emissions. In order to avoid distortion of the markets, international guidance documents were established that allow the assessment of emissions and the description of emission explaining variables in a consistent way (greenhouse gases: IPCC, 2006; air pollutants: EMEP/EEA, 2009).

Emissions have to be reported as consistent time series for the period from 1990 onwards. For key sources, calculations and reporting have to be detailed. Hence fattening pigs will be treated more sophisticated than boars.

At present, an attempt is being made to better describe emissions from pig production, including the description of feed composition (Dämmgen et al., 2011), updating emission factors (Dämmgen et al., 2010a) and technical measures to reduce emissions from houses (Dämmgen et al., 2010b).

All emission rates are related to excretion rates. These are depending on feed intake rates which are governed by the energy and nutrient requirements of the respective animals.

This work describes in detail the assessment of the energy requirements in pig production. It is restricted to the fraction of energy that can be metabolized (metabolizable energy, ME).

Hitherto, the assessment of energy requirements in pig production in the German agricultural emission inventory was based on data provided in GfE (1987). Meanwhile, the respective data were updated and the methods improved (GfE, 2006). The comprehensive revision of the description of emissions from pig production makes use of this new edition.

To a large extent, the literature used in GfE (2006) was published during the time span underlying the emission inventory (the years from 1990 onwards). Hence, it is assumed that the data and methods compiled in GfE (2006) are representative of the past two decades and that the calculation procedures derived from GfE (2006) are applicable to all the years since 1990.

This work applies and transforms the relations provided in GfE (2006) so that they meet the needs of the agricultural emission inventory.

2 Definition of pig subcategories

The assessment of energy requirements is carried out for animal populations with similar feeding. However, official German animal survey data rely on a differentiation of animals according to weights. Hence, the survey data have to be transformed to fit into energy requirement calculation routines. Table 1 compares the categories used in the official German survey and in the German emission inventory (see Haenel et al., 2010).

Table 1:
Pigs, categorization and characterization of subcategories

descriptor in the official survey	type[a]	subcategory in the emission inventory	weight 1[b] (in kg animal^{-1})	weight 2[b] (in kg animal^{-1})
piglets	---[c]	suckling-pigs	1.5	8
	we	weaners	8	*variable* $w_{\text{fin, we}}$
young pigs lighter than 50 kg live weight	fp	fattening pigs	*variable* $w_{\text{fin, we}}$	*variable* $w_{\text{fin, we}}$
fattening pigs 50 to 80 kg				
fattening pigs 80 to 110 kg				
fattening pigs heavier than 110 kg				
young sows gestating	so	sows	mean weight: 220	
other sows gestating				
young sows not gestating				
other sows not gestating				
boars	bo	breeding boars	mean weight: 200	

[a] type: code used to describe the animal categories in the German inventory.
[b] weight 1: weight at the beginning of the respective period, weight 2: weight at the end of the respective period; wfin: variable final weight.
[c] suckling-pigs do not constitute a separate animal category. They are accounted for within the calculations of energy and feed requirements of the sows (see Haenel et al., 2011)

The subcategory "sows" covers all subcategories of sows for breeding irrespective of their age and weight. The calculation of energy and feed requirements includes the suckling-pigs as they do not constitute a separate animal category in the inventory (see Haenel et al., 2011).

Weaners are young pigs between weaning and the beginning of fattening. In the emission inventory, this lifespan is assumed to begin at an animal weight of about 8 kg animal^{-1}. It ends with weights ranging from 25 to approx. 30 kg animal^{-1} (depending on year and region). Data for $w_{\text{fin, we}}$ are available for each year and district.

Fattening pigs are all pigs in the final fattening stages, i.e. with weights above about 25 to 30 kg animal^{-1} till slaughtering (105 to 120 kg animal^{-1} live weight). Again, data for $w_{\text{fin, fp}}$ are available for each year and district.

For sows a mean weight of 220 kg animal^{-1} is estimated as discussed below.

For breeding boars, a mean live weight of 200 kg animal^{-1} is assumed (expert judgment E. Schulz).

The categories used in the inventory are described in the subsequent chapters. The variable animal weights used in Table 1 for the inventory category "weaners" and "fattening pigs" are obtained from official statistics. The weight data for piglets are based on expert judgment, while the mean weights of sows and boars will be discussed in the respective chapters.

3 Sows

3.1 Total energy requirements during one reproduction cycle

The total metabolic energy (ME) requirements of a sow during one round, i. e. during one reproduction cycle, is given by Equation (1). It reflects that the reproduction cycle comprises two gestation phases, the lactation phase and the time span between weaning and covering.

$$\Sigma ME_{\text{sow}} = \Sigma ME_{\text{gest,1}} + \Sigma ME_{\text{gest,2}} + \Sigma ME_{\text{lact}} + \Sigma ME_{\text{wtc}} \quad (1)$$

where

ΣME_{sow} total metabolizable energy required for one round (MJ animal^{-1} round^{-1})

$\Sigma ME_{\text{gest, 1}}$ metabolizable energy required during gestation phase 1 (in MJ animal^{-1} round^{-1})

$\Sigma ME_{\text{gest, 2}}$ metabolizable energy required during gestation phase 2 (in MJ animal^{-1} round^{-1})

ΣME_{lact} metabolizable energy required during lactation (in MJ animal^{-1} round^{-1})

ΣME_{wtc} metabolizable energy required between weaning and covering (in MJ animal^{-1} round^{-1})

The phase-related energy requirements will be discussed in the subsequent chapters.

3.1.1 Energy requirements during gestation

The energy requirements for the development of the conception products, the uterus and the compensation of weight losses during the previous gestation have to be taken into account in addition to the energy requirements for maintenance (GfE, 2006, pg. 34f). The gestation phase can be subdivided into two separate phases with different means of daily ME requirements $ME_{\text{gest, 1}}$ and $ME_{\text{gest, 2}}$ (with j the index of day).

GfE (2006), Table 4.13, provides $ME_{\text{gest, 1}}$ and $ME_{\text{gest, 2}}$ data depending on the ordinal number of pregnancy and the weight loss during lactation. As no official statistics are available on these criteria, the GfE data have been averaged with identical weights yielding $ME_{\text{gest, 1}}$ = 33.3 MJ d^{-1} and $ME_{\text{gest, 2}}$ = 40.7 MJ d^{-1} for the respective periods.

The ME data in Table 4.13 in GfE (2006) represent the energy requirements when the sow is expected to give birth to 13 piglets. At present, this piglets number per litter marks the upper limit in German piglet production. Hence, the use of $ME_{\text{gest, 1}}$ and $ME_{\text{gest, 2}}$ would avoid underestimation of the energy requirements used for the construction of emission time series.

3.1.2 Energy requirements during lactation

During the lactation period, energy is required for maintenance and milk production. Equation (2) defines the total daily energy requirements for the sow-piglets system as it is applied in the inventory.

$$ME_{\text{lact, j}} = ME_{\text{m,sow, j}} + \eta_{\text{milk}} \cdot n_{\text{piglets, raised}} \quad (2)$$

where

$ME_{\text{lact, j}}$ daily metabolizable energy required on day j during lactation (in MJ animal^{-1} d^{-1})

j index of day

$ME_{\text{m, sow, j}}$ daily metabolizable energy required for maintenance on day j (in MJ animal^{-1} d^{-1}, see below)

η_{milk} specific metabolizable energy required for milk production (in MJ piglet^{-1} d^{-1}, see below)

$n_{\text{piglets, raised}}$ number of piglets raised per sow and birth (in piglet, see below)

The total energy requirements for maintenance during a gestation phase are calculated from the daily requirements for maintenance which are given in GfE (2006), pg. 23, Equation 7:

$$ME_{\text{m, sow, j}} = \eta_{\text{ME, m, sow}} \cdot w_{\text{met, j}} \quad (3)$$

where

$ME_{\text{m, sow, j}}$	metabolizable energy required for maintenance for day j (in MJ animal^{-1} d^{-1})
j	index of day
$\eta_{\text{ME, m, ,sow}}$	specific metabolizable energy required for maintenance ($\eta_{\text{ME, m, ,sow}}$ = 0.44 MJ per kg of metabolic weight, see footnote to Table 4.13 in GfE, 2006)
$w_{\text{met, j}}$	metabolic weight on day j (in kg animal^{-1})

The metabolic weight, $w_{\text{met, j}}$, is a function of animal weight [1]:

$$w_{\text{met, j}} = w_{\text{unit}} \cdot \left(\frac{w_{\text{sow, j}}}{w_{\text{unit}}} \right)^{0.75} \tag{4}$$

where

$w_{\text{met, j}}$	metabolic weight on day j (in kg animal^{-1})
$w_{\text{sow, j}}$	daily mean of live weight on day j (in kg animal^{-1}, see below)
w_{unit}	unit weight (w_{unit} = 1 kg animal^{-1})

In the inventory the daily mean of live weight, $w_{\text{sow, j}}$, is replaced by the sow weight averaged over the entire reproduction cycle, see Chapter 3.3.

The specific metabolizable energy required for milk production, η_{milk}, can be derived from the data provided in the footnotes to Table 4.17 in GfE (2006), pg. 81: production of milk per kg piglet weight gain (4.1 kg kg^{-1}), energy content of milk (5.0 MJ kg^{-1}), percentage of metabolizable energy used for milk production (70 %). These data lead to η_{milk} = 6.8 MJ piglet^{-1} d^{-1}, when being combined with an average estimate for daily piglet weight gain of 232 g piglet^{-1} d^{-1} which is obtained from birth and weaning weights and the duration of the lactation phase (see Table 2).

The number of piglets per litter can be deduced from the number of piglets raised per sow and year and the duration of a production cycle (see Table 2).

$$n_{\text{piglets, raised}} = n_{\text{piglets, year}} \cdot \frac{\tau_{\text{round}}}{\alpha} \tag{5}$$

where

$n_{\text{piglets, raised}}$	number of piglets raised per sow and birth (in piglet)
$n_{\text{piglets, year}}$	number of piglets raised per sow and year birth (in piglet)
τ_{round}	duration of piglet production cycle (in d round^{-1})
α	time units conversion factor (α = 365 d a^{-1})

[1] Formally, Equation (4) differs from the respective description given in GfE (2006), pg. 23, Equation 7, i. e. LM$^{0.75}$ where LM is animal weight. The term LM$^{0.75}$ would imply units of kg$^{0.75}$ which is not allowed in the SI system. This problem is avoided by Equation (4) which nevertheless yields the same numeric result like LM$^{0.75}$.

Note that Equation (2) does not explicitly account for the possible gains of metabolizable energy by weight losses during lactation and/or additional piglet feed (GfE, 2006, pg. 38) as there are no official statistical data to describe these contributions. However, Equation (2) covers a wide range of ME requirements data provided in Table 4.17 in GfE (2006). Hence it is assumed that, on average, Equation (2) describes the German situation adequately.

Table 2 lists results of Equation (2) obtained for a range of piglet numbers.

3.1.3 Energy requirements between weaning and covering

For the period between weaning and covering, GfE (2006), pg. 72, assume the same total daily energy requirements as for advanced gestation.

$$ME_{\text{wtc, j}} = ME_{\text{gest, 2}} \tag{6}$$

where

$ME_{\text{wtc, j}}$	daily metabolizable energy required during the phase "weaning to covering" (in MJ animal^{-1} d^{-1})
j	index of day
$ME_{\text{gest, 2}}$	daily metabolizable energy required during advanced gestation (in MJ animal^{-1} d^{-1}), see Chapter 3.1.1

3.2 Cumulative energy requirements and comparison with the former approach

Table 2 lists the daily requirements for the different phases (see Chapters 3.1.1 to 3.1.3) as well as the duration of the respective phases.

Table 2:
Sows, energy requirements as used in the inventory. For details see text.

phase	duration in d	number of piglets per sow per birth	energy requirements ***, revised approach in MJ animal^{-1} d^{-1}	energy requirements, former approach * in MJ animal^{-1} d^{-1}
gestation phase 1	84 *		33.3	25
phase 2	30 *		40.7	29
lactating	28 **	8	79.5	56
		9	86.3	
		10	93.1	67
		11	99.9	
		12	106.7	77
		13	113.5	
weaning to covering	27 *		40.7	29

* based on GfE (1987), see also Dämmgen et al. (2007);
** in connection with a weaning weight of 8 kg piglet-1 (expert judgment E. Schulz);
*** based on GfE (2006)

Table 2 also allows for a comparison with the values hitherto used which were based on GfE (1987) (see Dämmgen et al., 2007) and considerably fall below those obtained with the new approach.

The cumulative energy requirements, i. e. the total of energy required during one reproduction cycle, is provided in Table 3.

Table 3:
Sows, total of energy required during one reproduction cycle (ΣME_{sow})

number of piglets	8	9	10	11	12	13
ΣME_{sow} (in MJ animal^{-1} round^{-1})	7166	7331	7496	7661	7826	7992

3.3 Animal weights

3.3.1 Estimation of mean sow weight

In general, the live weight of a sow is not a constant during the reproduction cycle. The weight gain during gestation compensates the weight loss during lactation in the precedent reproduction cycle and comprises the weight gain of the conception products and the mammary gland as well as the weight gain of the sow itself. Table 4 shows typical weight change data (taken from Table 4.13 in GfE, 2006). A weight of 255 kg animal^{-1} is considered a typical final live weight (DLG, 2008, pg. 13).

Table 4:
Sows, animal weights (w_{sow}) and weight changes (Δw_{sow}) as a function of the number of gravidity (n_{gr}). All weight data in kg animal^{-1}.(Source: GfE, 2006, Table 4.13.)

Δw_{sow} during lactation	n_{gr}	1	2	3	4
0	w_{sow} at covering	140	185	225	255
	Δw_{sow} during gravidity	70	65	55	25
-10	w_{sow} at covering	140	185	225	255
	Δw_{sow} during gravidity	80	75	65	35
-20	w_{sow} at covering		185	225	255
	Δw_{sow} during gravidity		85	75	45

However, these weight changes cannot be accounted for in the inventory as the time span taken by one reproduction cycle is shorter than the inventory time step which is one year. Hence energy considerations for the inventory have to be based on a mean sow weight. Simply averaging the weights at covering as listed in Table 4 yields $2.1 \cdot 10^2$ kg animal^{-1}. However as this estimate may be biased by a relative under-representation of fully grown-up sows, the inventory assumes a mean sow weight of $2.2 \cdot 10^2$ kg animal^{-1}, which is the arithmetic mean of the weights at covering for the second and the fourth gestation. It ignores the lowest weight in order to roughly compensate for the under-represented highest weight.

3.3.2 Mean piglet weights at birth and weaning

For piglets, the inventory is based on a birth weight of 1.5 kg piglet^{-1}. This can be derived from feeding recommendations in DLG (2008), Table 4.1, where the piglet weight after the first week with a daily weight gain of 0.2 kg piglet^{-1} d^{-1} reaches 2.9 kg piglet^{-1}.

According to expert judgment (E. Schulz) the typical weaning weight is assumed to be 8 kg piglet^{-1} in connection with a lactation phase duration of 28 days (see Table 2).

4 Weaners

For weaners, the metabolic energy requirements comprise the requirements for both maintenance and growth. They are calculated according to the recommendations in GfE (2006).

$$\Sigma ME_{\mathrm{we}} = \sum_{j=1}^{k_{\mathrm{fin}}} \tau_{\mathrm{day}} \cdot ME_{\mathrm{m,\,we,\,j}} + \sum_{j=1}^{k_{\mathrm{fin}}} \tau_{\mathrm{day}} \cdot ME_{\mathrm{g,\,we,\,j}} \qquad (7)$$

where

ΣME_{we}	total metabolizable energy required (MJ animal^{-1} round^{-1})
j	index of day
k_{fin}	number of the final day of the weaners' life span
τ_{day}	unit time period (τ_{day} = 1 d round^{-1})
$ME_{m, we, j}$	metabolizable energy required for maintenance for day j (in MJ animal^{-1} d^{-1})
$ME_{g, we, j}$	metabolizable energy required for growth for day j (in MJ animal^{-1} d^{-1})

4.1 Daily energy requirements

Daily energy requirements for maintenance with weaners are defined as follows (cf. discussion Chapter 3.1.2).

$$ME_{\mathrm{m,\,we,\,j}} = \eta_{\mathrm{ME,\,m,\,we}} \cdot w_{\mathrm{unit}} \cdot \left(\frac{w_{\mathrm{we,j}}}{w_{\mathrm{unit}}}\right)^{0.75} \qquad (8)$$

where

$ME_{m, we, j}$	metabolizable energy required for maintenance for day j (in MJ animal^{-1} d^{-1})
j	index of day
$\eta_{ME, m, we}$	specific metabolizable energy required for maintenance ($\eta_{ME, m, we}$ = 1.25 · 0.44 MJ kg^{-1} d^{-1}, GfE, 2006, pg. 23)
$w_{we, j}$	mean weaner live weight on day j (in kg animal^{-1})
w_{unit}	unit weight (w_{unit} = 1 kg animal^{-1})

The energy required daily for growth is calculated according to:

$$ME_{\mathrm{g,\,we,\,j}} = \eta_{\mathrm{ME,\,g,\,we,\,j}} \cdot \left(\frac{\Delta w}{\Delta t}\right)_{\mathrm{we,\,j}} \qquad (9)$$

where

- $ME_{\mathrm{g,\,we,\,j}}$ metabolizable energy consumed for daily growth on day j (in MJ animal^{-1} d^{-1})
- j index of day
- $\eta_{\mathrm{ME,\,g,\,we,\,j}}$ specific metabolizable energy required for growth on day j (in MJ kg^{-1}, see below)
- $(\Delta w/\Delta t)_{\mathrm{we,\,j}}$ daily weight gain per animal and day j (in kg animal^{-1} d^{-1})

The specific metabolizable energy required for growth is a function of protein and fat gains, hence a function of age:

$$\eta_{\mathrm{ME,\,g,\,we,\,j}} = \frac{\alpha_{\mathrm{p,\,we}} \cdot P_{\mathrm{we}} + \alpha_{\mathrm{f,\,we}} \cdot F_{\mathrm{we,\,j}}}{k_{\mathrm{pf,\,we}}} \qquad (10)$$

where

- $\eta_{\mathrm{ME,\,g,\,we,\,j}}$ day-dependent specific metabolizable energy required for growth (in MJ kg^{-1})
- j index of day
- $\alpha_{\mathrm{p,\,we}}$ energy content of protein ($\alpha_{\mathrm{p,\,we}}$ = 23.8 MJ kg^{-1}, see GfE, 2006, pg. 32)
- $\alpha_{\mathrm{f,\,we}}$ energy content of fat ($\alpha_{\mathrm{f,\,we}}$ = 39.7 MJ kg^{-1}, see GfE, 2006, pg. 33)
- $k_{\mathrm{pf,\,we}}$ partial efficiency ($k_{\mathrm{pf,\,we}}$ = 0.7 MJ MJ^{-1}, see GfE, 2006, pg. 33)
- P_{we} constant ratio of protein gain to weight gain (P_{we} = 0.17 kg kg^{-1}, see GfE, 2006, pg. 29)
- $F_{\mathrm{we,\,j}}$ day-dependent ratio of fat gain to weight gain (in kg kg^{-1}, see below)

According to GfE (2006), pg. 30, the fat content is about 110 g kg^{-1} for a live weight of 10 kg and 170 g kg^{-1} for a live weight of 30 kg. From this the following linear equation is deduced:

$$F_{\mathrm{we,\,j}} = a_{\mathrm{F,\,we}} + b_{\mathrm{F,\,we}} \cdot w_{\mathrm{we,\,j}} \qquad (11)$$

where

- $F_{\mathrm{we,\,j}}$ day-dependent ratio of fat gain to weight gain (in kg kg^{-1})
- j index of day
- $a_{\mathrm{F,\,we}}$ constant ($a_{\mathrm{F,\,we}}$ = 0.08 kg kg^{-1})
- $b_{\mathrm{F,\,we}}$ constant ($b_{\mathrm{F,\,we}}$ = 0.003 kg^{-1} animal)
- $w_{\mathrm{we,\,j}}$ mean weaner live weight on day j (in kg animal^{-1})

4.2 Cumulative energy requirements and animal weights

According to Equation (7), the energy requirements have to be calculated separately for each single day to obtain the cumulative energy requirements. This would require about 50 calculation steps.

However, Equation (7) can be transformed into an integral equation yielding the cumulative energy requirements in just one calculation step. This transformation presupposes the knowledge about the development of the daily weight gain rate. The latter is a function of animal weight as shown in Figure 1.

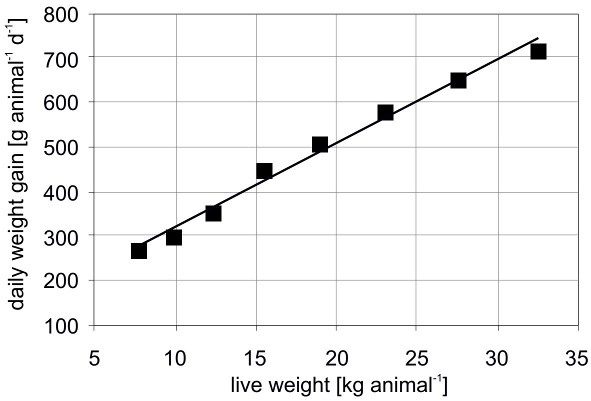

Figure 1:

Weaners, weight gain as a function of live weight. Exemplary variable data: squares (LfL, 2004); solid line: linear approximation.

Calculations made for comparison purposes with the total energy summation equation given above show that, without a relevant error, the total energy may also be calculated based on the assumption of a constant (i. e. mean) weight gain rate.

Integration then leads to a relation for the ME amount required for maintenance and growth between animal weights $w_{\mathrm{we,\,0}}$ and $w_{\mathrm{we,\,1}}$ (for details see Appendix):

$$\Sigma ME_{\mathrm{we}}(w_{\mathrm{we,\,0}}, w_{\mathrm{we,\,1}}) = \eta_{\mathrm{ME,\,m,\,we}} \cdot \frac{w_{\mathrm{unit}}^2}{1.75 \cdot g} \cdot \left[\left(\frac{w_{\mathrm{we,\,1}}}{w_{\mathrm{unit}}}\right)^{1.75} - \left(\frac{w_{\mathrm{we,\,0}}}{w_{\mathrm{unit}}}\right)^{1.75}\right] + \eta^{*}_{\mathrm{ME,\,g,\,we}} \cdot (w_{\mathrm{we,\,1}} - w_{\mathrm{we,\,0}}) \qquad (12)$$

where

- $\Sigma ME_{\mathrm{we}}(w_{\mathrm{we,\,0}}, w_{we,\,1})$ ME required for the phase between the weights $w_{\mathrm{we,\,0}}$ and $w_{\mathrm{we,\,1}}$ (in MJ animal^{-1} round^{-1})
- $\eta_{\mathrm{ME,\,m,\,we}}$ specific metabolizable energy required for maintenance (in MJ kg^{-1} d^{-1})
- w_{unit} unit weight (w_{unit} = 1 kg animal^{-1})
- $w_{\mathrm{we,0}}$, $w_{\mathrm{we,1}}$ animal weights limiting a special phase between weaning and fattening, with $w_{\mathrm{we,\,0}} < w_{\mathrm{we,\,1}}$ (in kg animal^{-1})
- g mean daily weight gain during the entire period between weaning and fattening (in kg animal^{-1} d^{-1})

and

$$\eta^*_{\mathrm{ME,\,g,\,we}} = \frac{1}{k_{\mathrm{pf,\,we}}} \cdot \left[\alpha_{\mathrm{p,\,we}} \cdot P_{\mathrm{we}} + \alpha_{\mathrm{f,\,we}} \cdot \left(a_{\mathrm{F,\,we}} + b_{\mathrm{F,\,we}} \cdot \frac{w_{\mathrm{we,\,0}} + w_{\mathrm{we,\,1}}}{2} \right) \right] \quad (13)$$

where

$\eta^*_{\mathrm{ME,\,g,\,we}}$ effective specific metabolizable energy required for growth, to be used for the entire period between weaning and fattening (in MJ kg^{-1})
$\alpha_{\mathrm{p,\,we}}$ energy content of protein ($\alpha_{\mathrm{p,\,we}}$ = 23.8 MJ kg^{-1}, see GfE, 2006, pg. 32)
$\alpha_{\mathrm{f,\,we}}$ energy content of fat ($\alpha_{\mathrm{f,\,we}}$ = 39.7 MJ kg^{-1}, see GfE, 2006, pg. 33)
$k_{\mathrm{pf,\,we}}$ partial efficiency ($k_{\mathrm{p,\,we}}$ = 0.7 MJ MJ^{-1}, see GfE, 2006, pg. 33)
P_{we} constant ratio of protein gain to weight gain (P_{we} = 0.17 kg kg^{-1}, see GfE, 2006, pg. 29)
$a_{\mathrm{F,\,we}}$ constant ($a_{\mathrm{F,\,we}}$ = 0.08 kg kg^{-1}, see Equation (11))
$b_{\mathrm{F,\,we}}$ constant ($b_{\mathrm{F,\,we}}$ = 0.003 kg^{-1} animal , see Equation (11))
$w_{\mathrm{we,0}}$, $w_{\mathrm{we,1}}$ animal weights limiting a special fattening phase, with $w_{\mathrm{we,\,0}} < w_{\mathrm{we,\,1}}$ (in kg $animal^{-1}$)

The results obtained with this one-step calculation procedure are almost identical with the multi-step approach using Equation (7). The difference is in the range of 0.0002 %.

Equation (12) can be used to calculate the energy requirements of single feeding phases. It requires the knowledge of weights rather than days as is the case with Equation (7). This is in line with the fact that information regarding phase feeding of weaners is based on animal weights.

The initial weaner weight is identical to the weight of a suckling-pig at the end of the lactation period. In the inventory, it is assumed to be 8 kg $animal^{-1}$. The final weight of the weaners' production phase equals the start weight of the fattening process. It is in the range of about 25 kg $animal^{-1}$ to 33 kg $animal^{-1}$. A typical mean value of the daily growth rate is 420 g $animal^{-1}$ d^{-1} (KTBL, 2008, pg. 636).

Exemplary total energy requirements for a start weight of 8.5 kg $animal^{-1}$, an average final weight of 29 kg $animal^{-1}$ and a mean weight gain of 420 g $animal^{-1}$ d^{-1} are 516.4 MJ $animal^{-1}$.

4.3 Comparison with the former approach

Figure 2 displays daily ME requirements data provided in GfE (1987), pg. 54, compared to respective data as calculated with Equation (12) based on GfE (2006).

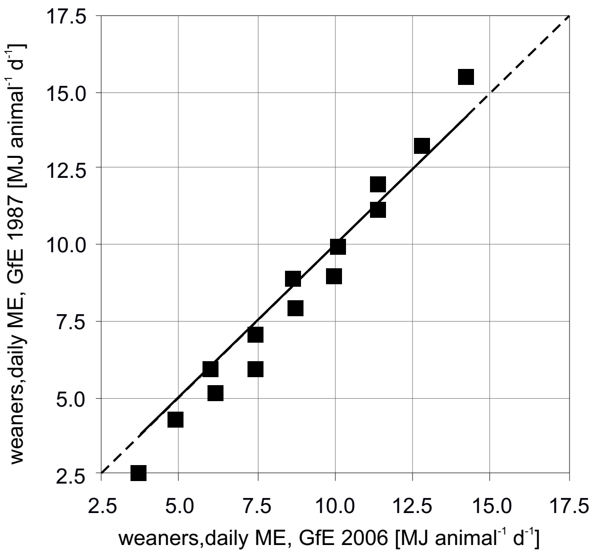

Figure 2:

Weaners, daily ME requirements, GfE (1987) data compared to calculations according to Equation (12) based on GfE (2006). Dotted line: 1 to 1 line; solid line: regression (intercept: 0, slope: 0.9952, R^2 = 0.953).

From Figure 2 we state that for the range of ME requirements typical for the early 1990ies there is no substantial difference between the ME recommendations given in GfE (1987) und GfE (2006). Thus, the inventory makes use of the GfE (2006) calculation method for the entire time series from 1990 onwards.

5 Fattening pigs

For fattening pigs, the metabolic energy (ME) requirements comprise the requirements for both maintenance and growth. The total ME required for a fattening period is given by

$$\Sigma ME_{\mathrm{fp}} = \sum_{j=1}^{k_{\mathrm{fin}}} \tau_{\mathrm{day}} \cdot ME_{\mathrm{m,\,fp,\,j}} + \sum_{j=1}^{k_{\mathrm{fin}}} \tau_{\mathrm{day}} \cdot ME_{\mathrm{g,\,fp,\,j}} \quad (14)$$

where

ΣME_{fp} total metabolizable energy required (in MJ $animal^{-1}$ $round^{-1}$)
k_{fin} number of the final day of the fattening period
τ_{day} unit time period (τ_{day} = 1 d $round^{-1}$)
j index of day
$ME_{\mathrm{m,\,fp,\,j}}$ metabolizable energy required for maintenance for day j (in MJ $animal^{-1}$ d^{-1})
$ME_{\mathrm{g,\,fp,\,j}}$ metabolizable energy required for growth for day j (in MJ $animal^{-1}$ d^{-1})

5.1 Daily energy requirements

The daily energy requirement for maintenance is defined by (cf. discussion Chapter 3.1.2):

$$ME_{\mathrm{m,\,fp,\,j}} = \eta_{\mathrm{ME,\,m,\,fp}} \cdot w_{\mathrm{unit}} \cdot \left(\frac{w_{\mathrm{fp,\,j}}}{w_{\mathrm{unit}}}\right)^{0.75} \qquad (15)$$

where

$ME_{\mathrm{m,\,fp,\,j}}$ metabolizable energy required for maintenance for day j (in MJ animal^{-1} d^{-1})
$\eta_{\mathrm{ME,\,m,\,fp}}$ specific metabolizable energy required for maintenance (in MJ kg^{-1} d^{-1}, see below)
$w_{\mathrm{fp,\,j}}$ live weight on day j (in kg animal^{-1})
w_{unit} unit weight (w_{unit} = 1 kg animal^{-1})

According to GfE (2006), pg. 23, the specific energy for maintenance can be described by

$$\eta_{\mathrm{ME,\,m,\,fp}} = \eta_{\mathrm{ME,\,m,\,fp,\,n}} \cdot \left(a_{\mathrm{m}} - b_{\mathrm{m}} \cdot \frac{w_{\mathrm{fp,\,j}} - w_{\mathrm{B}}}{w_{\mathrm{A}} - w_{\mathrm{B}}}\right) \qquad (16)$$

where

$\eta_{\mathrm{ME,\,m,\,fp}}$ specific metabolizable energy required for maintenance (in MJ kg^{-1} d^{-1})
$\eta_{\mathrm{ME,\,m,\,fp,\,n}}$ reference value of specific metabolizable energy for maintenance ($\eta_{\mathrm{ME,\,m,\,fp,\,n}}$ = 0.44 MJ kg^{-1} d^{-1}, GfE, 2006, pg. 23)
a_{m} constant (a_{m} = 1.25 MJ MJ^{-1})
b_{m} constant (b_{m} = 0.25 MJ MJ^{-1})
$w_{\mathrm{fp,\,j}}$ live weight on day j (in kg animal^{-1})
$w_{\mathrm{A}}, w_{\mathrm{B}}$ thresholds animal weights (in kg animal^{-1}, see below)

GfE (2006) uses w_{A} = 30 kg animal^{-1} and w_{B} = 100 kg animal^{-1}. GfE (2006) applies Equation (16) also to animal weights falling below w_{A} and exceeding w_{B}. Then, in case of animal weights smaller than w_{A}, the term in brackets is set equal to a_{m}, while for weights larger than w_{B} it equals $a_{\mathrm{m}} - b_{\mathrm{m}}$.

The energy required for growth is calculated according to:

$$ME_{\mathrm{g,\,fp,\,j}} = \eta_{\mathrm{ME,\,g,\,fp,\,j}} \cdot \left(\frac{\Delta w}{\Delta t}\right)_{\mathrm{fp,\,j}} \qquad (17)$$

where

$ME_{\mathrm{g,\,fp,\,j}}$ metabolizable energy required for daily growth on day j (in MJ animal^{-1} d^{-1})
j index of day
$\eta_{\mathrm{ME,\,g,\,fp,\,j}}$ specific metabolizable energy required for growth on day j (in MJ kg^{-1}, see below)
$(\Delta w/\Delta t)_{\mathrm{fp,\,j}}$ daily weight gain per animal and day j (in kg animal^{-1} d^{-1})

The specific energy requirements for growth, $\eta_{\mathrm{ME,\,g,\,fp,\,j}}$, is a function of protein and fat gains, which means, it is also a function of life time:

$$\eta_{\mathrm{ME,\,g,\,fp,\,j}} = \frac{\alpha_{\mathrm{p}}}{k_{\mathrm{p}}} \cdot P_{\mathrm{j}} + \frac{\alpha_{\mathrm{f}}}{k_{\mathrm{f}}} \cdot F_{\mathrm{j}} \qquad (18)$$

where

$\eta_{\mathrm{ME,\,g,\,fp,\,j}}$ specific metabolizable energy required for growth on day j (in MJ kg^{-1})
j index of day
α_{p} energy content of protein (α_{p} = 23.8 MJ kg^{-1}, see GfE, 2006, pg. 32)
α_{f} energy content of fat (α_{f} = 39.7 MJ kg^{-1}, see GfE, 2006, pg. 33)
k_{p} partial efficiency (k_{p} = 0.56 MJ MJ^{-1}, see GfE, 2006, pg. 33)
k_{f} partial efficiency (k_{f} = 0.74 MJ MJ^{-1}, see GfE, 2006, pg. 33)
P_{j} day-dependent ratio of protein gain to weight gain (in kg kg^{-1}, see below)
F_{j} day-dependent ratio of fat gain to weight gain (in kg kg^{-1}, see below)

The relative protein gain P is obtained from the Equation (8) in GfE (2006) differentiated with respect to animal weight.

$$P_{\mathrm{j}} = a_{\mathrm{P}} - b_{\mathrm{P}} \cdot w_{\mathrm{fp,\,j}} \qquad (19)$$

where

P_{j} day-dependent ratio of protein gain to weight gain (in kg kg^{-1}, see below)
j index of day
a_{P} constant (a_{P} = 0.168 kg kg^{-1})
b_{P} constant (b_{P} = 0.0001828 kg^{-1} animal)
$w_{\mathrm{fp,\,j}}$ live weight on day j (in kg animal^{-1})

Differentiation of Equation (9) in GfE (2006) with respect to animal weight yields the relative fat gain F. A correction factor of 0.94 kg kg^{-1} has to be taken into account (GfE, 2006, pp. 28 and 31).

$$F_{\mathrm{j}} = a_{\mathrm{F}} \cdot (b_{\mathrm{F}} + c_{\mathrm{F}} \cdot w_{\mathrm{fp,\,j}}) \qquad (20)$$

where

F_{j} day-dependent ratio of fat gain to weight gain (in kg kg^{-1})
j index of day
a_{F} constant (a_{F} = 0.94 kg kg^{-1})
b_{F} constant (b_{F} = 0.1162 kg kg^{-1})
c_{F} constant (c_{F} = 0.002778 kg^{-1} animal)
$w_{\mathrm{fp,\,j}}$ live weight on day j (in kg animal^{-1})

5.2 Cumulative energy requirements and animal weights

By analogy to the procedure used for weaners (see Chapter 4.2) the summation formula (14) is transformed into an equation that allows to calculate the cumulative metabolizable energy by one single calculation step rather than summing up daily energy requirements with more than a hundred single steps (for details of the transformation process see Appendix).

In order to account for the fact that the specific metabolizable energy $\eta_{ME, m}$ is defined separately for the animal weight intervals "falling below 30 kg animal^{-1}", "30 to 100 kg animal^{-1}" and "exceeding 100 kg animal^{-1}", the transformation has to be performed separately for these intervals.

As for weaners, the transformation is performed under the assumption of a constant (i.e. mean) weight gain rate (cf. also Dämmgen et al., 2009, pg. 178). Integration then leads to an equation for the amount of ME required for the growth between animal weights w_0 and w_1, where w_0 and w_1 represent $w_{fp, 0}$ and $w_{fp, 1}$, respectively:

$$\Sigma ME_{fp}(w_0, w_1) = \eta_{ME, m, n} \cdot \left[\frac{\varphi_1(w_0, w_1, w_A) + \varphi_2(w_0, w_1, w_A, w_B) + \varphi_3(w_0, w_1, w_B)}{g} \right] + \eta^*_{ME, g} \cdot (w_1 - w_0) \quad (21)$$

where

$ME_{fp}(w_0, w_1)$ ME required for the fattening phase between the weights w_0 and w_1 (in MJ animal^{-1} ME)
$\eta_{ME, m, n}$ reference value of specific metabolizable energy for maintenance ($\eta_{ME, m, n}$ = 0.44 MJ kg^{-1} d^{-1}, GfE, 2006, pg. 23)
w_0, w_1 animal weights limiting a special fattening phase, with $w_0 < w_1$ (in kg animal^{-1} ME)
w_A, w_B thresholds of animal weight (in kg animal^{-1}, see Chapter 5.1)
g mean daily weight gain during the entire fattening period (in kg animal^{-1} d^{-1})

and

$$\varphi_1 = \frac{a_m \cdot w_{unit}^2}{1.75} \cdot \left[\left(\frac{\min(w_1, w_A)}{w_{unit}} \right)^{1.75} - \left(\frac{\min(w_0, w_A)}{w_{unit}} \right)^{1.75} \right] \quad (22)$$

$$\varphi_2 = \frac{w_{unit}^2}{1.75} \cdot \left(a_m + \frac{b_m \cdot w_A}{w_B - w_A} \right) \cdot \left[\left(\frac{\max(w_A, \min((w_1, w_B))}{w_{unit}} \right)^{1.75} - \left(\frac{\min(w_B, \max(w_0, w_A))}{w_{unit}} \right)^{1.75} \right] - \frac{b_m \cdot w_{unit}^3}{2.75 \cdot (w_B - w_A)} \cdot \left[\left(\frac{\max(w_A, \min(w_1, w_B))}{w_{unit}} \right)^{2.75} - \left(\frac{\min(w_B, \max(w_0, w_A))}{w_{unit}} \right)^{2.75} \right] \quad (23)$$

$$\varphi_3 = \frac{w_{unit}^2}{1.75} \cdot \left[\left(\frac{\max(w_1, w_B)}{w_{unit}} \right)^{1.75} - \left(\frac{\max(w_0, w_B)}{w_{unit}} \right)^{1.75} \right] \quad (24)$$

$$\eta^*_{ME, g} = \frac{\alpha_p}{k_p} \cdot \left(a_P - b_P \cdot \frac{w_0 + w_1}{2} \right) + \frac{\alpha_f}{k_f} \cdot a_F \cdot \left(b_F + c_F \cdot \frac{w_0 + w_1}{2} \right) \quad (25)$$

where

$\varphi_1, \varphi_2, \varphi_3$ functions of w_0, w_1, w_A, and w_B (in kg^2 animal^{-2})
w_0, w_1 animal weights limiting a special fattening phase, with $w_0 < w_1$ (in kg animal^{-1})
w_A, w_B animal weight thresholds (in kg animal^{-1}, see Chapter 5.1)
w_{unit} unit weight (w_{unit} = 1 kg animal^{-1})
a_m constant (a_m = 1.25 MJ MJ^{-1}, GfE, 2006, pg. 23)
b_m constant (b_m = 0.25 MJ MJ^{-1}, GfE, 2006, pg. 23)
$\eta^*_{ME, g}$ mean specific metabolizable energy required for growth, see above (in MJ kg^{-1})
α_p coefficient (α_p = 23.8 MJ kg^{-1}, see GfE, 2006, pg. 32)
k_p coefficient (k_p = 0.56 MJ MJ^{-1}, see GfE, 2006, pg. 33)
a_P constant (a_P = 0.168 kg kg^{-1}, see above)

b_P	constant (b_P = 0.0001828 kg^{-1} animal, see above)
α_f	coefficient (α_f = 39.7 MJ kg^{-1}, see GfE, 2006, pg. 33)
k_f	coefficient (k_f = 0.74 MJ MJ^{-1}, see GfE, 2006, pg. 33)
a_F	constant (a_F = 0.94 kg kg^{-1}, see above)
b_F	constant (b_F = 0.1162 kg kg^{-1}, see above)
c_F	constant (c_F = 0.002778 kg^{-1} animal, see above)

Again, exemplary comparisons between the results obtained with the application of Equations (14) and (21) ff shows a perfect agreement (relative deviation 0.0001 %).

According to the data compilation in Haenel et al. (2010), Chapter 5.5.1.2, the initial weight of fattening pigs is in the range of about 25 kg animal^{-1} to 33 kg animal^{-1} while the final weight is between 105 kg animal^{-1} and 120 kg animal^{-1}; averaging the daily growth rate over the two decades from 1990 on and over all federal states yields about 680 g animal^{-1} d^{-1}.

Exemplary total energy requirements for a mean start weight of 29 kg animal^{-1}, a mean final weight of 113 kg animal^{-1} and a mean daily weight gain of 680 g animal^{-1} d^{-1} (with a resulting fattening period duration of 124 days) are 3,3 GJ animal^{-1}.

5.3 Comparison with the former approach

Figure 3 displays daily ME requirements data provided in GfE (1987), pg. 35, compared to respective data as calculated with Equation (21) according to GfE (2006).

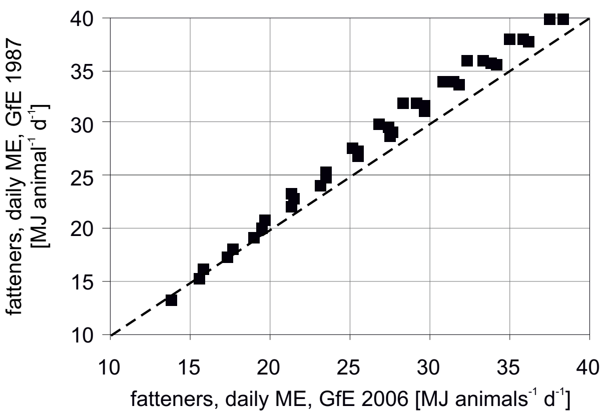

Figure 3:

Fatteners, daily ME requirements, GfE (1987) data compared to calculations according to Equation (21) based on GfE (2006) (squares). Dotted line: 1 to 1 line.

The ME requirements as calculated using the GfE (1987) approach exceed those obtained with Equation (21) based on GfE (2006) by up to 12 %. GfE (2006), pg. 27 ff, explain this with the different experimental data available. However, the 2006 GfE edition is based on data published since 1980 which leads to the assumption that the energy requirements recommendations in this edition should be appropriate to describe the situation in the years covered by the inventory, i. e. the past two decades.

6 Breeding boars

For breeding boars, the metabolic energy requirements comprise the requirements for both maintenance and growth. However, as the contribution of boars to the overall emissions from pig husbandry is almost negligible, the inventory simply assumes all boars counted by the official survey to be breeding boars whose weight gain is restricted (GfE, 2006, pg. 84).

Due to the breeding boars' limited importance and the scarcity of data (GfE, 2006, pg. 84) the inventory does not attempt to model energy requirements of boars. While GfE (1987), pg. 68, suggested mean ME requirements of 30 MJ animal^{-1} d^{-1}, GfE (2006), pg. 84, recommends a range of 30 to 35 MJ animal^{-1} d^{-1}. A rough estimate based on the data provided in GfE (2006), pg. 83, and the use of ME calculation approach for fattening pigs indicates that the value of 35 MJ animal^{-1} d^{-1} matches a mean boar weight of about 200 kg animal^{-1} (expert judgment E. Schulz) better than 30 MJ animal^{-1} d^{-1}. Hence the inventory assumes daily ME requirements of 35 MJ animal^{-1} d^{-1} leading to cumulative annual requirements of 12775 MJ animal^{-1} a^{-1}.

7 Conclusions

It is good practice to use the best data available to construct emission inventories. For pigs, the national situation had formerly been reflected in a data set published in GfE (1987) with background information dating from the 1970s and early 1980s. The updated methodologies and data published in GfE (2006) were a remarkable step forward with respect to the reliability and accuracy of the German agricultural emission inventory. The use of equations rather than tables allows for a simpler treatment of variable energy requirement calculations.

For the most important subcategory, i.e. fattening pigs, the application of the updated GfE (2006) methodology results in reduced energy requirements, hence in reduced excretion rates for faeces and urine und subsequently reduced emissions. The opposite is the case for sows, weaners and boars, but this is outweighed by the reductions achieved for fattening pigs.

Acknowledgement

The authors express their thanks to Dr Edgar Schulz, co-author of GfE (2006) for his detailed and constructive review.

Appendix: Derivation of a closed mathematical description of the cumulative ME requirements of weaners

Cumulative energy requirements can be calculated by adding up daily requirements over the time span considered:

$$\Sigma ME_{\mathrm{we}} = \sum_{\mathrm{j}=1}^{\mathrm{k_{fin}}} \tau_{\mathrm{day}} \cdot ME_{\mathrm{we,\,j}} \qquad \text{(A1)}$$

where

ΣME_{we}	total metabolizable energy required between weaning and fattening (in MJ animal^{-1} round^{-1} ME)
τ_{day}	unit time period (τ_{day} = 1 d round^{-1})
j	index of day
$\mathrm{k_{fin}}$	number of the final day of the weaners' life span
$ME_{\mathrm{we,\,j}}$	metabolizable energy required for maintenance and growth on day j (in MJ animal^{-1} d^{-1} ME)

In the German agricultural inventory, equations had been derived using data in GfE (1987) that expressed a sum like Equation (A1) in a single equation using a fitted power series (Dämmgen et al., 2007). The latter had to be replaced with the use of new data according to GfE (2006). It was decided to base the derivation of a new single equation on mathematical integration instead of fitting power series.

As a preparation for the mathematical solution, Equation (A1) has to be rewritten as difference quotient:

$$\left.\frac{\Delta(\Sigma ME_{\mathrm{we}})}{\Delta \tau}\right|_{\mathrm{j}} = ME_{\mathrm{we,\,j}} = ME(w_{\mathrm{we,\,j}}) \qquad \text{(A2)}$$

where

$\Delta(\Sigma ME_{\mathrm{we}})$	increment of total metabolizable energy required between weaning and fattening (in MJ animal^{-1} round^{-1} ME)
$\Delta\tau$	time increment ($\Delta\tau = \tau_{\mathrm{day}}$ = 1 d round^{-1})
j	index of day
$ME_{\mathrm{we,\,j}}$	metabolizable energy required for maintenance and growth on day j (in MJ animal^{-1} d^{-1} ME)
$w_{\mathrm{we,\,j}}$	mean weaner live weight on day j (in kg animal^{-1})

It is plausible that this procedure is valid not only for daily time steps but also for infinitesimally small time steps. Hence the difference quotient can be transformed in a differential quotient for each time τ'_{k}. Here, τ' is a compartmentalized time scale (in s round^{-1}) that is connected to the timescale τ (in d round^{-1}) by a time units conversion factor.

$$\left.\frac{\mathrm{d}(\Sigma ME_{\mathrm{we}})}{\mathrm{d}\tau'}\right|_{\tau'_{\mathrm{k}}} = \gamma^{-1} \cdot ME(w_{\mathrm{we}}(\tau'_{\mathrm{k}})) = f(\tau') \qquad \text{(A3)}$$

where

$(\Sigma ME_{\mathrm{we}})$	increment of total metabolizable energy required between weaning and fattening (in MJ animal^{-1} round^{-1} ME)
τ'	time (in s round^{-1})
τ'_{k}	specific time (in s round^{-1})
γ	time units conversion factor (γ = 86400 s d^{-1})
$w_{\mathrm{we}}(\tau'_{\mathrm{k}})$	mean weaner live weight at time τ'_{k} (in kg animal^{-1})

and

$$f(\tau') = \gamma^{-1} \cdot \left\{ a \cdot (w_{\mathrm{we}})^{\mathrm{b}} + \left[c + \left(d \cdot w_{\mathrm{we}} + e\right)\right] \cdot g \right\} \qquad \text{(A4)}$$

where

$f(\tau')$	metabolizable energy required per animal and second (in MJ animal^{-1} s^{-1} ME)
γ	time units conversion factor (γ = 86400 s d^{-1})
a, b, c, d, e, g	see text below
$w_{\mathrm{we}} = w_{\mathrm{we}}(\tau')$	time dependent mean weaner live weight (in kg animal^{-1})

The entities a, b, c, d, e and g originate from the comparison of the equations describing the energy requirements for maintenance and growth (Chapter 4.1). In particular, g denotes a constant growth rate.

Integration of $f(\tau')$ leads to the cumulative energy requirements:

$$\Sigma ME_{\mathrm{we}} = \int_0^{\tau'_1} f(w_{\mathrm{we}}(\tau'))\,\mathrm{d}\tau' \qquad \text{(A5)}$$

where

ΣME_{we}	total metabolizable energy required between weaning and fattening (in MJ animal^{-1} round^{-1} ME)
τ'	time (in s round^{-1})
$f(w_{\mathrm{we}}(\tau'))$	metabolizable energy required per animal and second (in MJ animal^{-1} s^{-1} ME)
$w_{\mathrm{we}}(\tau')$	time dependent mean weaner live weight (in kg animal^{-1})

and

$$\tau'_1 = \gamma \cdot \mathrm{k_{fin}} \cdot \tau_{\mathrm{day}} \qquad \text{(A6)}$$

where

τ'_1	time of the end of the weaners' life span (in s round^{-1})

γ	time units conversion factor (γ = 86400 s d^{-1})
k_{fin}	number of the final day of the weaners' lifespan
τ_{day}	unit time period (τ_{day} = 1 d $round^{-1}$)

The entity g can be used in Equation (A5) to substitute the independent variable time by weight

$$\Sigma ME_{we} = \frac{\gamma}{g} \cdot \int_{w_{we,0}}^{w_{we,1}} f(w_{we})\, dw_{we} \quad (A7)$$

where

ΣME_{we}	total metabolizable energy required between weaning and fattening-period (in MJ $animal^{-1}$ $round^{-1}$ ME)
γ	time units conversion factor (γ = 86400 s d^{-1})
g	animal weight gain per unit time (in kg $animal^{-1}$ d^{-1})
$f(w_{we})$	metabolizable energy required per animal and second (in MJ $animal^{-1}$ s^{-1} ME)
w_{we}	mean weaner live weight (in kg $animal^{-1}$)
$w_{we, 0}$	mean weaner live weight at weaning (in kg $animal^{-1}$)
$w_{we, 1}$	mean weaner live begin at the end of the fattening period (in kg $animal^{-1}$)

Execution of the integral and subsequent re-substitution of the entities a, b, c, d, e and g in $f(w_{we})$ results in Equation (12) in Chapter 4.2.

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Estimating numbers of piglets, weaners and fattening pigs for the German agricultural emission inventory

Hans-Dieter Haenel*, Ulrich Dämmgen*, and Claus Rösemann*

Abstract

The establishment of emission inventories presupposes animal populations that are homogeneous with respect to feeding and management. For weaners and fattening pigs, the official surveys for pigs do not meet these requirements. Hence, the official animal numbers have to be redistributed to serve this purpose. In this paper, the algorithms to derive the animal categories of the emission inventory (weaners, fattening pigs) from survey data (piglets below 20 kg, young pigs lighter than 50 kg, fattening pigs 50 to 80 kg, fattening pigs 80 to 110 kg, fattening pigs heavier than 110 kg) are defined. Also, the calculation of the mean population of suckling-pigs needed for the redistribution of official animal numbers is described.

The updated animal populations result in decreased overall emissions from pig husbandry in the German emission inventory.

Keywords: pigs, emission inventory

Zusammenfassung

Ableitung der Tierzahlen von Saugferkeln, Aufzuchtferkeln und Mastschweinen für das deutsche Emissionsinventar

Die Erstellung von Emissionsinventaren setzt Tierpopulationen voraus, die hinsichtlich Fütterung und Haltung homogen sind. Diese Eigenschaft weisen die in den amtlichen Tierzählungen verwendeten Schweinekategorien für Aufzuchtferkel und Mastschweine nicht auf, so dass die erhobenen Tierzahlen für die Inventarerstellung erst nach einer Umverteilung zwischen den Kategorien verwendbar sind. Die Algorithmen zur Umrechnung der Schweinekategorien der Tierzählung (Ferkel unter 20 kg, Jungschweine bis unter 50 kg, Mastschweine 50 bis 80 kg, Mastschweine 80 bis 110 kg, Mastschweine 110 kg und mehr) in Kategorien des Emissionsinventars (Aufzuchtferkel, Mastschweine) werden abgeleitet. Die zu diesem Zweck erforderliche Berechnung der mittleren Saugferkelpopulation wird ebenfalls beschrieben.

Die Neuberechnung der Populationen der im deutschen Emissionsinventar verwendeten Schweinekategorien führt zu verringerten Emissionen aus der Schweinehaltung insgesamt.

Schlüsselwörter: Schweine, Emissionsinventar

* Johann Heinrich von Thünen Institute (vTI), Institute for Agricultural Climate Research, Bundesallee 50, 38116 Braunschweig, Germany

1 Introduction

Emission inventories are constructed to serve as policy advice. As such they allow for the description of the present situation. They also provide a tool for the establishment of scenarios. Furthermore, they are the key instrument in emission reporting. For the latter purpose, emission inventories have to be compiled according to international guidance documents. The assessment of emissions and the description of emission explaining variables have to be accomplished in a consistent way (greenhouse gases: IPCC, 1996, and IPCC, 2000; air pollutants: EMEP/EEA, 2009). Time series have to be produced for all relevant entities from 1990 onwards.

The treatment of emission sources and the respective calculation procedures vary with the relative importance of the source: important sources (such as fattening pigs) have to be dealt with using detailed procedures, whereas minor sources (such as boars) can be treated with simpler methodologies.

In the agricultural emission inventory, emissions are calculated using the basic relation

$$E_{\mathrm{i}} = n_{\mathrm{i}} \cdot EF_{\mathrm{i}}$$

that describes an emission E_{i} as the product of the activity n_{i} and the emission factor EF_{i}. n_{i} and EF_{i} form a matching pair. All elements of n_{i} must have the same properties that result in the same emission factor per element. Hence, the first step in the description of emissions from animal husbandry is to identify those populations that are homogeneous with respect to their feed.

Official surveys of pigs in Germany do not reflect production practices, in particular feeding practices, but report livestock numbers by weights and ages and – to some extent – sex.

Other than in the inventory, where suckling-pigs are treated together with the sows, and weaners form a separate category, official surveys do not distinguish between suckling-pigs and weaners. In these surveys suckling-pigs and weaners are counted together as "piglets".

"Young pigs" between 20 and 50 kg animal^{-1} form a subcategory in the survey. However, their feeding changes at weights of 25 to 33 kg animal^{-1}, depending on federal state and year. In the inventory this weight level constitutes the differentiation between weaners and fattening pigs.

Hence there is the need to re-calculate survey subcategories for the use in the emission inventory for suckling-pigs, weaners and fattening pigs.

Within the comprehensive updating of all aspects of pig production (see Dämmgen et al., 2010a (emission factors), Dämmgen et al., 2010b (air scrubbers), Dämmgen et al., 2011 (feed and excretion rates), and Haenel et al., 2011 (energy requirements)) it became obvious that the treatment of pig categories in former emission inventories (e.g. Dämmgen et al., 2009) was inadequate and that a partial redistribution of the animal subcategories of the livestock survey into inventory subcategories had to be developed. The new adjustment approaches are presented in this work.

Table 1:
Pigs, categorisation and characterization (Haenel et al., 2011, modified)

Animal subcategory according to official survey		Animal subcategories used in the inventory			
type	subcategory	type [a]	subcategory	weight 1 [b] (in kg animal^{-1})	weight 2 [b]
M	piglets below 20 kg	sp	suckling-pigs	1.5	8
		we	weaners	8	25 - 33 [c]
N	young pigs lighter than 50 kg live weight				
O	fattening pigs 50 to 80 kg	fp	fattening pigs	25 - 33 [c]	105 - 120 [d]
P	fattening pigs 80 to 110 kg				
Q	fattening pigs heavier than 110 kg				
R	young sows gestating	so	sows	mean weight: 220	
S	other sows gestating				
T	young sows not gestating				
U	other sows not gestating				
V	boars	bo	breeding boars	mean weight: 200	

[a] type: codes used to describe the animal categories in the German livestock survey of pigs and in the German emission inventory
[b] weight 1: weight at the beginning of the respective period, weight 2: weight at the end of the respective period
[c] see Table 3
[d] see data compilation in Haenel et al. (2010)

2 Pig subcategories in the German livestock survey and the German emission inventory

In the official German statistics, pigs are categorised according to their sex, weight, destination and age. For the emission inventory, subcategories have to be formed that are homogeneous with respect to feeding (Haenel et al., 2010). Table 1 compares the categories used in the livestock survey and in the inventory.

In the emission inventory, the category "sows" covers all subcategories of sows for breeding irrespective of their age and weight and is based on a concept that considers a sow and its suckling-pigs as a unit with respect to the calculation of energy and feed requirements. For birth and weaning weights of suckling-pigs the inventory uses typical values (1.5 kg animal^{-1} and 8 kg animal^{-1}, respectively, see Haenel et al., 2011).

Weaners are young pigs between weaning and the beginning of fattening at about 25 to 33 kg animal^{-1}.

All pigs with weights above this weight threshold, until slaughtering at ca. 105 to 120 kg animal^{-1} live weight, fall into the inventory subcategory "fattening pigs".

For breeding boars, a mean live weight of 200 kg animal^{-1} is assumed (Haenel et al., 2011).

The following three equations are derived from Table 1:

$$n_{\mathrm{sp}} + n_{\mathrm{we}} + n_{\mathrm{fp}} = n_{\mathrm{M}} + n_{\mathrm{N}} + n_{\mathrm{O}} + n_{\mathrm{P}} + n_{\mathrm{Q}} \quad (1)$$

$$n_{\mathrm{so}} = n_{\mathrm{R}} + n_{\mathrm{S}} + n_{\mathrm{T}} + n_{\mathrm{U}} \quad (2)$$

$$n_{\mathrm{bo}} = n_{\mathrm{V}} \quad (3)$$

where

$n_{\mathrm{M}}, \ldots, n_{\mathrm{V}}$ number of animals in the categories M to V of the German livestock survey (see Table 1) (in place)
n_{sp} number of suckling-pigs in the inventory (in place)
n_{we} number of weaners in the inventory (in place)
n_{fp} number of fattening pigs in the inventory (in place)
n_{so} number of sows in the inventory (in place)

The German official survey counts animals at a qualifying date. In the inventory, these animal numbers are interpreted as occupied animal places. The inventory assumes that the number of occupied animal places is constant within a year, an assumption which is necessary as the inventory time step of one year does not allow for intra-annual changes of livestock numbers.

These animal places are equivalent to the elements of the populations as defined by IPCC (1996), pg. 4.7. Hence, in the following the unit "place" will be used rather than "animal".

While Equations (2) and (3) directly yield the animal numbers for sows (n_{so}) and boars (n_{bo}) as needed in the inventory, the relationships underlying Equation (1) need further processing in order to separately obtain the animal numbers of suckling-pigs (n_{sp}), weaners (n_{we}) and fattening pigs (n_{fp}).

Table 2:

Number of piglets raised per sow and year, $n_{\mathrm{piglet, year}}$ (primary statistical information) BW: Baden-Württemberg; BY: Bayern; BB: Brandenburg; HE: Hessen; MV: Mecklenburg-Vorpommern; NI: Niedersachsen; NW: Nordrhein-Westfalen; RP: Rheinland-Pfalz; SL: Saarland; SN: Sachsen; ST: Sachsen-Anhalt; SH: Schleswig-Holstein; TH: Thüringen; StSt: Stadtstaaten (total of Hamburg, Bremen and Berlin)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
BW									19.20	19.10	18.20	18.67	18.90	17.89		20.00	20.50	21.10	
BY	18.00	18.00	17.70	17.60	17.80	18.50	17.60	18.40	19.60	19.60	19.60	19.40	19.60	19.60		20.40	19.90	20.10	
BB								17.80	18.20	18.90	19.50	19.70		20.30	20.80	21.70	22.20	22,50	22.80
HE	17.00	17.10	16.60	16.90	17.10	17.10	16.90	17.90	18.00	18.60	18.50		19.10	19.00	19.90	21.10	21.60	21.20	
MV								19.10	19.60	20.80	21.10		21.30					23.29	23.84
NI	18.90	18.90	18.90	18.70	18.50	18.70	18.40	18.90	19.30	19.50	19.70		19.60	20.30	20.60	21.30	21.40	21,20	
NW	19.00	17.80	18.40	18.90	19.00	18.90	19.10	19.70	20.10	20.20	20.30	20.40	20.30	20.30	21.80	22.10		22.60	
RP	17.20	17.30	17.20	17.30	17.40	17.50	17.60	17.90	18.00	18.20	18.50		18.40	19.10	19.00				
SL	17.20	17.30	17.20	17.30	17.40	17.50	17.60	17.90	18.00	18.20	18.50		18.40	19.10	19.00				
SN				17.80	18.40	18.70	18.64	19.18	19.88	20.41	20.45	20.56	20.67	21.04	21.40	21.49	22.38	23.40	23.31
ST								18.50	18.50	19.90	20.00	19.60	20.66	20.52	21.01	21.46	22.00	22.26	22.99
SH		18.80	18.60	18.40	18.70	19.00	18.80	19.30	19.70	19.80	20.10		20.30	20.70	21.60	22.60		23.20	
TH							18.30	19.00	20.10	20.45	21.23	20.43	21.25	20.78	21.66	22.19	22.72	23.28	23.94
StSt																			
Germany		18.50	18.50				19.10	19.10				19.80	19.80						

For data sources see Haenel et al. (2010)

3 Suckling-pigs

In the emission inventory (Haenel et al., 2010), suckling-pigs are considered a unity with their sows ("sow plus litter") and the emissions reported for sows include those of their suckling-pigs. The underlying energy requirement calculations (see Haenel et al., 2011) take the number of suckling-pigs into account. As the official livestock survey of pigs does not provide numbers of the suckling-pig population, the inventory uses the number of piglets raised per sow and year collated from various sources (see Haenel et al., 2010) as shown in Table 2.

The number n_M of piglets below a weight of 20 kg animal^{-1} as counted in the official livestock survey of pigs includes the suckling-pigs. Hence, in order to avoid double counting of the suckling-pig population, their number has to be estimated and subtracted from n_M when estimating the number of animals in the inventory subcategory of weaners (see Chapter 4).

3.1 Former approach

In the former approach (e.g. Dämmgen et al., 2009), the number of suckling-pigs was derived from the number of piglets raised per sow (as shown in Table 2) assuming a fixed number of births of 2.2 a^{-1}, in agreement with KTBL (2004). No attempt was made to relate the resulting numbers to the number of piglets provided by the official livestock survey of pigs and subtract the population of suckling-pigs from the officially counted number n_M.

3.2 New approach

The data in Table 2 can be used to derive the annual mean of the suckling-pig population at the federal state level:

$$n^*_{\text{sp}} = n_{\text{so}} \cdot n_{\text{piglet, year}} \cdot \frac{\tau_{\text{sp}}}{\alpha} \qquad (4)$$

where

n^*_{sp}	annual mean of the suckling-pig population at the federal state level (in place)
n_{so}	number of sows (in place), see below,
$n_{piglet, year}$	number of piglets raised per sow and year (in place place^{-1} a^{-1}), see Table 2
τ_{sp}	duration of lactation (τ_{sp} = 28 d, see Haenel et al., 2011)
α	time units conversion factor (α = 365 d a^{-1})

In the inventory the number of sows is given by Equation (2). Figure 1 displays n^*_{sp} in relation to the officially reported piglets number (n_M) where n^*_{sp} data points have been calculated for all federal states and years as far as the input data have been available (see Table 2).

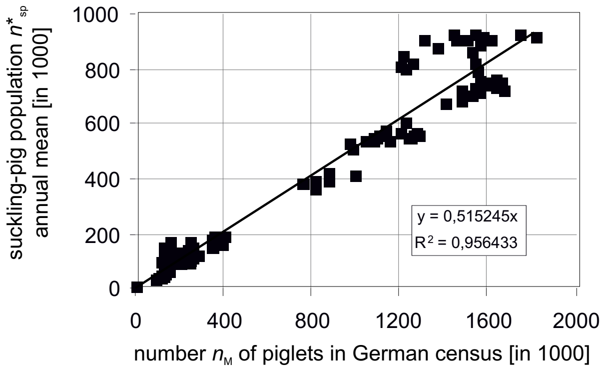

Figure 1:
Mean population of suckling-pigs (n^*_{sp}) over piglets number in the official livestock survey (n_M) at the federal state level. Linear regression: slope 0.5771, R^2 = 0.96.

In order to obtain a robust method to estimate the numbers of suckling-pigs from the number of piglets provided by the official livestock survey, a linear regression with zero intercept was applied to the n^*_{sp} data displayed in Figure 1, yielding

$$n_{\text{sp}} = c_{\text{sp}} \cdot n_{\text{M}} \qquad (5)$$

where

n_{sp}	number of suckling-pigs to be used in the inventory (in place)
c_{sp}	constant (c_{sp} = 0.5771 place place^{-1})
n_M	number of place in official livestock survey (in place), see Table 1

In the inventory, Equation (5) is applied to data at the district level. A non-zero intercept would not improve results.

4 Weaners

4.1 Former approach

Previous inventories (e.g. Dämmgen et al., 2009) wrongly assumed that suckling-pigs were not included in the number of piglets reported in the official livestock survey. Instead, all piglets officially counted as "piglets up to 20 kg animal^{-1}" were attributed to the inventory subcategory "weaners",

$$n_{\text{we, old}} = n_{\text{M}} \qquad (6)$$

where

$n_{we, old}$	number of weaners in the former approach (in place)
n_M	animal number of type M (etc.) in official livestock survey (in place), see Table 1

4.2 New approach

The numbers n_M of piglets (see Table 1) provided by the statistical offices of the federal states (StatLA C III 1 – vj/xx 4 with, xx denoting the year of the census) comprise the numbers of suckling-pigs (n_{sp}, see Chapter 3) and of weaners up to an animal weight of 20 kg animal^{-1}. As the final weight of weaners is substantially higher than 20 kg animal^{-1} (see Chapter 2) a certain share of the inventory animal category "weaners" must be included in the officially reported numbers of young pigs (n_N, see Table 1). This is reflected by the following relation:

$$n_{we} = n_M - n_{sp} + n_{we,x} \qquad (7)$$

where

n_{we} number of weaners in the new approach (in place)
n_M number of piglets in official livestock survey (in place)
n_{sp} number of suckling-pigs (in place), see Equation (5)
$n_{we,x}$ share of officially counted young pigs regrouped into the inventory subcategory of weaners (in place)

The share of officially counted young pigs to be regrouped into the inventory subcategory of weaners is given by

$$n_{we,x} = x_{we,x} \cdot n_N \qquad (8)$$

where

$n_{we,x}$ share of officially counted young pigs regrouped into the inventory subcategory of weaners (in place)
$x_{we,x}$ fraction (in place place^{-1}) with $0 \le x_{we,x} \le 1$
n_N number of young pigs in German census (in place)

No official data on animal numbers is available to derive the fraction $x_{we,x}$. However, as animal weight data are known, the plausible assumption of a continuous animal growth rate allows for the construction of the following simple estimate of $x_{we,x}$:

$$x_{we,x} = \frac{w_{we,fin} - w_{yp,start}}{w_{yp,fin} - w_{yp,start}} \qquad (9)$$

where

$x_{we,x}$ fraction (in place place^{-1}) with $0 \le x_{we,x} \le 1$
$w_{we,fin,}$ weaner weight at the end of the production period (in kg animal^{-1}), see Table 3
$w_{yp,start}$ lower weight boundary of the official subcategory of young pigs ($w_{yp,start}$ = 20 kg animal^{-1}, see Table 1)
$w_{yp,fin}$ upper weight boundary of the official subcategory of young pigs ($w_{yp,start}$ = 50 kg animal^{-1}, see Table 1)

The data available on the final weight of weaners, $w_{we,fin}$, is shown in Table 3. Based on these data, $x_{we,x}$ amounts to about one third.

Table 3:
Weaners, final weights $w_{we,fin}$ (in kg animal^{-1})

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
BW	28	28	28	28	29	29	30	29	29.3		29.9		29.5		30	30	30.9	32.3	
BY	27	28	28	28	29	29	29	29	29	29	29.4	29.6	29.8	28.3			30.4	30	
BB								27	27	27	27	27	27				28	28	
HE	26	27	27	27	27	28	28	28	28	29	29	29	30				30		
MV								28	27	27	27	27	27				28.8	29	
NI	25.5	26	26	27	28	28.5	28.5	28.5	28.5	29	29	29	28.5	30	30	30	30		
NW	24	24	25	26	27	27	27	28	28	28	28	28	28	28	28	29	29.1	30	
RP	25	26	26	27	28	28	28	29	28	29	30	31	33	31	32	32.3	33.5		
SL	25	26	26	27	28	28	28	29	28	29	30	31	33	31					
SN				28	27			28	28	28	27	27	27				28.8	29.8	
ST																			
SH	25	25	26	26	27	28	28	28	28	28	28	28	28	29	29	29.5	29.8	30	
TH							28	27	28	28	28	27	27				28.0	28.5	27.5
StSt																			
Germany																			

(for abbreviations BW, BY, etc., see Table 2)
For data sources see Haenel et al. (2010)

Table 4:
Numbers of weaners (in 1000 places), calculated with the former and new approaches

year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
former approach	4986.2	4483.2	4501.8	4432.9	4101.3	3869.5	4013.2	4098.2	4381.9	4578.5
new approach	5789.1	4245.5	4236.5	4319.5	4241.9	4140.3	4150.8	4415.5	4694.5	4691.6
year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
former approach	4611.2	4612.7	4586.5	4506.9	4753.5	4739.7	4782.5	4138.5		
new approach	4640.7	4672.4	4781.4	4762.8	4767.0	4973.8	5047.0	5193.7	5003.8	

Table 4 compares the weaner numbers obtained with the former approach to those based on the new approach. In most years the latter exceed the numbers obtained with the former approach. However, as the animal numbers in the new approach depend both on the suckling-pig population and the young pig population and as the fluctuations of both populations are only loosely correlated, it is possible within the new approach to yield weaner numbers falling below those obtained with the former approach.

5 Fattening pigs

5.1 Former approach

Hitherto (e.g. Dämmgen et al., 2009), the subcategory "fattening pigs" comprised the officially reported populations for young pigs between 20 and 50 kg live weight (n_N), fattening pigs 50 to 80 kg (n_O), fattening pigs 80 to 110 kg (n_P) and fattening pigs heavier than 110 kg (n_Q).

$$n_{\text{fp, old}} = n_N + n_O + n_P + n_Q \tag{10}$$

where
$n_{\text{fp, old}}$ number of fattening pigs in the former approach (in place)
n_N etc. animal numbers of type N (etc.) in official livestock survey (in place), see Table 1

As a consequence, the former approach ignored that fattening commences at weights between about 25 and 33 kg animal^{-1} (see Table 3).

5.2 New approach

The redistribution of animals considers that a share of the young pigs' population is to be attributed to the weaners' population:

$$\begin{aligned} n_{\text{fp}} &= n_N + n_O + n_P + n_Q - n_{\text{we, x}} = \\ & n_N \cdot (1 - x_{\text{we, x}}) + n_O + n_P + n_Q \end{aligned} \tag{11}$$

where
n_{fp} number of fattening pigs (in place)
n_N etc. animal numbers of type N (etc.) in official livestock survey (in place), see Table 1
$n_{\text{we, x}}$ share of officially counted young pigs regrouped into the inventory category of weaners (in place), see Chapter 4.2
$x_{\text{we, x}}$ fraction (in place place^{-1}) with $0 \le x_{\text{we, x}} \le 1$, see Chapter 4.2

In many years the ratio of n_N to the total of n_O, n_P, and n_Q is in the order of one half. Hence, considering that $x_{\text{we, x}}$ amounts to about one third, n_{fp} can be estimated to be lower than the total of n_N, n_O, n_P and n_Q by the order of one tenth. The exact reduction of the numbers of fattening pigs as obtained by the new approach can be seen from the comparison shown in Table 5.

Table 5:
Numbers of fattening pigs (in 1000 places), calculated with the former and new approaches

year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
former approach	20033.9	16322.8	16675.0	16527.9	15851.3	15326.7	15642.2	15961.9	16990.5	16485.0
new approach	17407.8	14921.2	15294.2	15020.4	14211.1	13641.0	14037.1	14146.1	15075.7	14697.8
year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
former approach	16202.9	16542.1	16810.2	16333.5	17138.9	16883.4	17405.9	16625.0		
new approach	14510.9	14455.7	14686.7	14956.8	14425.5	15180.5	14843.0	15246.0	15270.3	

6 Summary and conclusions

A consistent approach has been derived to redistribute officially counted numbers of piglets, young pigs and fattening pigs into the animal categories of the emission inventory, i. e. weaners and fattening pigs.

The new model avoids the double counting of suckling-pigs in the former approach where suckling-pigs were taken into account within the unit sow/suckling-pigs but also in the category of weaners. It also results in modified numbers of weaners and, in any case, reduced numbers of fattening pigs, as shown in Tables 4 and 5.

Clearly, elimination of animal double counting reduces the calculated emissions. Further reductions of the calculated emissions are achieved by assigning a share of the officially counted young pigs to the weaner subcategory instead of the fattener subcategory as emissions per weaner are smaller than those per fattening pig (see Haenel et al, 2010).

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Probabilistic analysis of coughs in pigs to diagnose respiratory infections

Anna-Lena Giesert*, Wolf-Tilo Balke*, and Gerhard Jahns**

Abstract

In Germany alone, respiratory infections in pigs fattening farms cause losses of millions of Euros. These economic losses are attributed less to total losses due to the death of pigs, but much more to costs for treatment and indirect costs caused by diminished mast und breeding results. The earlier infected animals are detected, the more promising treatments and means to reduce the risk of infection are. Therefore it is necessary to distinguish between coughs from healthy pigs, simple throat cleaning, and coughs by infected pigs. This paper shows that this is automatically possible, and that even the kind of infection can be distinguished. Methods and procedures applied are mainly adapted from those which successfully have been proved in human speech recognition.

Keywords: Pigs, livestock breeding; respiratory diseases; bioacoustics; biosemiotic; signal analysis; Hidden Markov Models (HMM)

Zusammenfassung

Probabilistische Analyse von Hustengeräuschen zur Diagnose von Atemwegserkrankungen bei Schweinen

Infektiöse Atemwegserkrankungen führen allein in Deutschland zu Millionenverlusten in der Schweinezucht. Diese ökonomischen Einbußen sind weniger durch Totalverluste infolge des Verendens der Tiere bedingt, sondern resultieren aus indirekten Verlusten durch die Beeinträchtigungen des Mast- und Zuchterfolges. Je früher erkrankte Tiere erkannt werden, umso erfolgversprechender sind der Behandlungserfolg und Maßnahmen zur Verminderung der Ansteckungsgefahr. Dazu ist es aber notwendig, das Husten eines gesunden Tieres von dem eines erkrankten zu unterscheiden. Der Beitrag zeigt, dass dies automatisch möglich ist, ja dass sich sogar die Art der Infektion erkennen lässt. Dabei kommen, entsprechend angepasst, Methoden und Verfahren zum Einsatz, wie sie sich in der Spracherkennung bewährt haben.

Schlüsselwörter: Schweine, Tierhaltung, Atemwegserkrankungen, Bioakustik, Biosemiotik, Signalanalyse, Hidden-Markov-Modelle (HMM)

* Technische Universität Braunschweig, Institute for Information Systems, Mühlenpfordtstraße 23, 38106 Braunschweig, Germany, Email: balke@ifis.cs.tu-bs.de

** Johann Heinrich von Thünen Institute (vTI), Federal Research Institute for Rural Areas, Forestry and Fisheries, Institute of Agricultural Technology and Biosystems Engineering, Bundesallee 50, 38116 Braunschweig, Germany,

1 Introduction

Respiratory infections in pig fattening farms due to *Protobacteria* of the *Pasteurellaceae* family (*Actinobacillus* spec. and *Pasteurella* spec.) cause losses of millions of Dollars or Euros (Scheidt, 1993), beside aspects of animal welfare. These economic losses are attributed less to total losses due to death of pigs, but much more to costs for treatment and indirect costs caused by diminished weight gain and breeding results (Hoy, 1994; Arbeitsgruppe Schwein, 2004). Farmers are reluctant to apply antibiotics as a precaution, not only because of the costs but also because of the risk that the final product, the meat, may contain antibiotic residues.

However, respiratory infections are fast-spreading diseases, which demand treatment as early as possible and fast action to prevent further infections in the herd. This means, the earlier an infection is detected, the better the chances of successful curing and containment of the infection are. In general cough may serve as an early clinical sign of a pig's respiratory tract infection.

The objective is, therefore, to develop software capable of automatically detecting coughing and of distinguishing between morbid coughs and coughs of healthy pigs. The latter also cough from time to time because of inhaled dust, as a kind of throat cleaning. This software would be a basis for a system to monitor a stable as a whole. In general, acoustic monitoring has several advantages in animal breeding: It is neither invasive nor is physical contact necessary. It does not disturb the normal behaviour of the animals and allows continuous monitoring of many animals. The costs are negligible. The software presented here makes use of methods which have proved successful in human speech recognition. The primary focus was to distinguish between morbid and healthy coughs, assuming that the first would effect on the whole respiratory tract, while the latter mainly affects the upper part, thus resulting in generally distinguishable sounds. However, during our experiments it turned out that it is even possible to distinguish between certain kinds of common infections, namely *Pasteurella* and *Actinobacillus*. Obviously, reliable automatically generated evidence pointing to certain infections is a valuable step in disease control, because the respective pigs can be tested and medicated faster. Thus, economic losses in sound monitored facilities could be reduced.

2 Material and methods

2.1 Data

The recorded and labelled data were provided by the courtesy of the Department of Biosystems, Measure, Model & Manage Bioresponses (M3-BIORES), Catholic University of Leuven in Belgium. The recordings contain three different manually labelled types of coughs. Data of the first type are coughs recorded from pigs; derived from a hybrid commercial strain (Landrace × Large White + Danish Duroc boar) at the beginning of the fattening period (100 days old and approx. 40 kg lbw), infected with *Pasteurella multocida*. Records from pigs, suffering from Actinobacillus pleuropneumoniae (three months old and 26 to 35 kg lbw), belonged to a hybrid line by a cross between Italian Landrace × Large White × Duroc. The first and second types of coughs were made under field conditions, in stables. (For more details see Ferrari et al., 2008) The artificially generated coughs were recorded under laboratory conditions, to guaranty, that the pigs (Belgian Landrace of both sexes about 15 kg) were really healthy. Citric acid was evaporated to elicit coughs by irritating the respiratory tract of healthy pigs (throat cleaning). (For more details see Moreaux et al., 1999) Already here, it has to be mentioned, that this inhomogeneity may result in an impairment of the significance of the results.

For training, validating and final testing, 232 *Pasteurella* coughs, 160 *Actinobacillus* coughs, and 149 artificially generated coughs were available. 70 % of each data type was used for training, whereas 30 % was used for validation of the recognition rate.

2.2 Data cleaning

As stated above, the morbid cough recordings contain ambient noises, since they were recorded in a stable. In the case of *Pasteurella* and *Actinobacillus* infections, these background noises were similar. But the artificially induced coughs lack these typical stable noises. This holds the risk of misclassification, because the classifier may be trained more on background noises than on cough types. Therefore the ambient noise had to be reduced as much as possible. Especially the sounds of ventilators or rattling chains are characterized by high frequencies, in contrast to the dominant low frequencies of coughs. Therefore we used a low pass filter to cut off high frequencies. Comparing filtered copies and unfiltered original data sets for training and evaluation purposes it turned out that the best cut-off frequency is 20 kHz, about 0.45 of the normalized Nyquist frequency of each signal. However, it must be mentioned that this analysis depends on human hearing. This implies that it cannot be guaranteed, that this cut-off frequency is optimal under all circumstances for the statistical models used later. In any case, as a result of this low pass filter, manual inspection showed clear coughs with only minimal ambient noise in most signals of the test set.

2.3 Feature extraction

Before coughs can be automatically classified, the significant characteristics of individual pig coughs have to be extracted from the recordings. We used a set of five well-known feature extraction methods and also combined their feature sets. Since all these methods only work on discrete spectra of the signals, we split each continuous signal into a set of equidistant frames. Each frame has a length of 11 ms, such that each frame can be regarded as a discrete stationary observation. Errors may occur when splitting the signal into frames, especially on the borders between frames (Scheithauer, 2005). Therefore we applied a Hamming Window to each frame to reduce such errors. Furthermore, all frames are slightly overlapped to guarantee smooth transitions. After discretization, the time-based signals had to be transformed to the frequency domain, because all extraction methods used in this work are based on spectra. The most popular algorithm for this is Discrete Fourier Transform (DFT) representing the signal by the integral over a sum of sine and cosine waves (Chirlian, 1994). A second method is the Discrete Cosine Transform (DCT), which works similarly to the DFT, but represents the signal in terms of a sum of cosine waves (Seibt, 2006; Stearns, 2002). We also used DCT as a baseline for our comparisons between feature accuracies.

Coughing sounds are very similar to each other, but are always strongly influenced by the pigs' vocal tracts. Thus, we used four features specifically designed for distinguishing vocalizations in speech recognition: the first pair is based on cepstral coefficients, the second pair is based on linear predictive coding. All algorithms for extraction were taken from the seminal work in Rabiner and Juang (1993). For the first pair we first extracted the spectral energy of a signal, the so-called cepstral coefficients, by applying a logarithmic dampening on the DFT. Then the Mel frequency cepstral coefficients (MFCCs), where all frequencies are mapped to the Mel-Scale in discrete steps such that the frequency bands are reduced, were extracted. A similar extraction was done for the Bark frequency spectral coefficients (BFCCs) with the Bark-Scale instead of the Mel-Scale. The use of both scales is justified due to the similarity of the vocal tract and the auditory system in mammals respecting the Weber-Fechner Law. The third feature used are the coefficients of linear predictive coding (LPC), which extracts typical speech parameters like pitch and vocal tract area. In particular LPC shows the degree of self-similarity of a signal, i.e., any frame can be represented as a linear combination of a fixed number of preceding frames, where all coefficients are assumed to be constant. As a last feature, the coefficients of perceptual linear predictive coding (PLPC) were extracted. In contrast to LPC, which is strongly dependent on the individual speaker, PLPC is speaker, respectively animal, independent. Basically, here all frequencies are first warped to the Bark-scale before extracting LPC coefficients (Hermansky, 1990).

Finally the first 20 coefficients of DCT, BFCC, MFCC, LPC and PLPC, respectively, were used as a feature vector. Each cough frame is represented by a vector containing all five features (i.e., a 100-dimensional feature vector) and each cough recording is represented as a concatenation of several feature vectors depending on its respective length.

2.4 Classification

The actual classification part was derived using Hidden Markov Models (HMMs), which have proven to be useful in speech recognition and also in animal call recognition, like calls from cows (Jahns, 2007), or birds (Wolff, 2008). Moreover, HMMs allow the time-independent modelling of signals and the differentiation of variations in the spectra for recognition independent of the individual speaker/vocalizing animal.

Generally speaking, a Hidden Markov Model is a doubly embedded stochastic process, where the states of the model are hidden (for more detailed information see e.g. Rabiner, 1989). Hidden Markov Models are typically used where the lengths of feature vectors vary from one to another. A Hidden Markov Model is characterized by: a set of distinguishable states, a matrix of transition probabilities from one state to another, a vector of observation symbol probabilities for each state, which is needed for the probability that a state generates an output and an initial state distribution. The challenge is to train a generic HMM to obtain the best fitting of these statistical parameters by samples. In our case the number of samples is the number of labelled coughs available. Because it is a statistical process, it is evident that the number of samples should be as great as possible. Each HMM has to be trained: in particular, the model parameters of the HMM are estimated by applying the well-known Baum-Welch Algorithm. The likelihood that the HMM has produced some observation (in our case a certain set of feature vectors representing a recording) can be determined using the Viterbi Algorithm, basically a linear programming algorithm to determine the most probable sequence of states for a given observation.

We used a simple left-right HMM for modelling cough sounds and inspected several spectrograms to get an intuition about the necessary number of states. Unfortunately there are no general rules to determine the number of states. So we used common heuristics: a first assumption was made by dividing cough sounds into at least three sections (heavy inhaling, strong cough, ebbing away) and allowing a transition from one state to the next, remaining in one state or skip one state, as shown in Figure 1. In our experiments we then varied the number of states from three to seven to check for the most suitable number of states showing the highest recognition rates. For each type of cough (*Pasteurella*, *Actinobacillus*, and non-morbid cough) an individual HMM was trained. To classify unknown cough sounds, the most likely HMM (i.e., the one best explaining the complete chain of observations) has to be computed. This procedure results in a three-way classifier whose correctness can be directly measured in the number of false classifications after evaluating all three hypotheses.

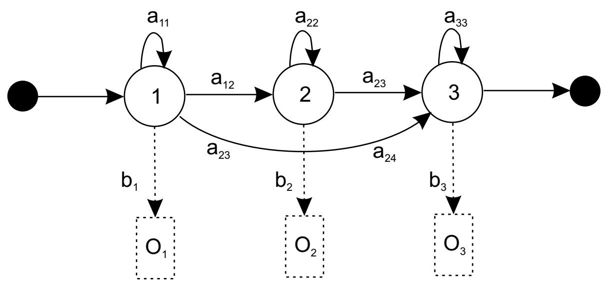

Figure 1:

A left-right HMM with three states. $\lambda = (\pi, A, B)$ initial state distribution (π), state transition probabilities (A), observation probability distribution (B).

3 Results

3.1 Total recognition rate

The experiments showed recognition rates for unknown recordings of more than 97 %. In particular, the HMMs trained with the original unfiltered data set reached 100 % recognition rate for *Pasteurella* coughs, 97.3 % for the *Actinobacillus* coughs and 98.4 % for the artificially generated coughs. Moreover, the representation of the states of the HMM was very good. The HMMs trained with the filtered data set reached even better recognition results than the models for the unfiltered data set, however, the representation of the states of this HMM was worse. It reaches 99 % recognition rate for the *Pasteurella* coughs, 100 % for the *Actinobacillus* coughs and 98.4 % for the artificially elicited coughs.

In summary both experiments, filtered and unfiltered, have shown that it is possible to accurately distinguish between artificially induced and morbid coughs, as well as between the two morbid cough types from pigs with *Pasteurella* or *Actinobacillus* infections.

3.2 Feature extraction

The experiments also confirmed that extraction methods designed for speech recognition are beneficial for cough classification. All individual features performed significantly better than general frequency-based features. DCT- features returned entirely unacceptable recognition rates of around 35 % (i.e., slightly better than random guessing) as shown in Figure 2. Still, the average recognition rate combining all features (including DCT) in one classifier was slightly higher than all other combinations of features. Thus, in combination with the other features the DCT feature still contributes to the excellent classification performance shown in Figure 3.

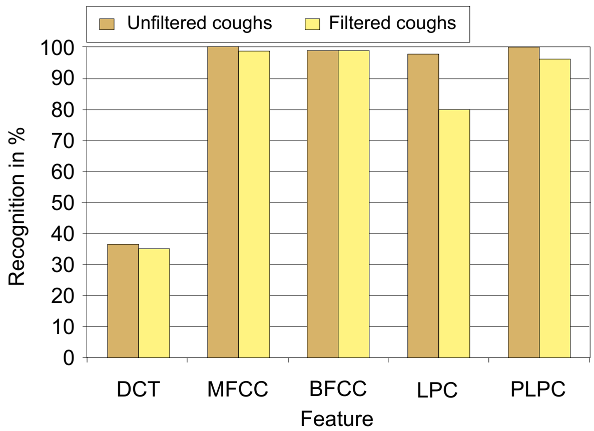

Figure 2:

Average percentage of correctly classified coughs with five different feature extraction methods

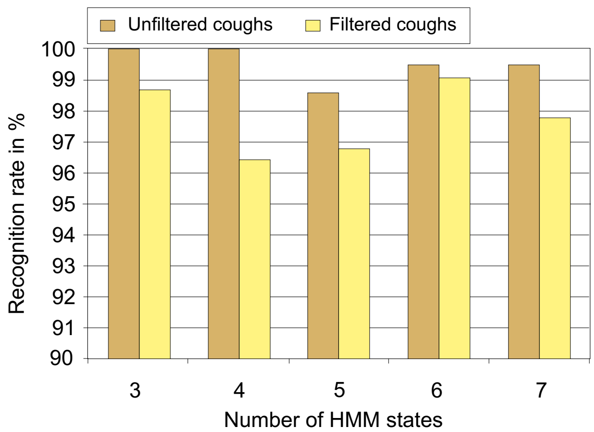

Figure 3:

Average recognition rate of filtered and unfiltered coughs for each tested HMM

3.3 Suitability of the Hidden Markov Models

The experiments showed that HMM with five states perform best for unfiltered data (see example classifications in Figure 4, 5 and HMM with six states for filtered data in Figure 6). Therefore, not only the recognition rate, but also the state representation is a crucial factor for finding the best HMM. For instance, a HMM for the unfiltered data set with a total recognition rate of 100 % and three states can be defined (see Figure 1). However, this first impression of perfect recognition may be misleading, because the state representation is entirely insufficient. As can be seen in Figure 4, coughs are always meaningfully divided into the different states. Beyond optimizing the recognition rate, it is important, especially for the model validity and extensibility, that this state representation is the same for all coughs, which indeed has similar reasons. Hence, some HMM (even with slightly better recognition rates over the test set) are still not suitable for a good classification because of their state representation. The recognition rates for all tested HMM can be seen in Figure 3. The few erroneously recognised unfiltered coughs were two *Pasteurella* coughs which were classified as *Actionbacillus* coughs and one artificially generated cough which was classified as *Actinobacillus* cough. Further, one filtered *Pasteurella* cough was classified as *Actionbacillus* cough and one filtered artificially generated cough was classified as *Actionbacillus* cough.

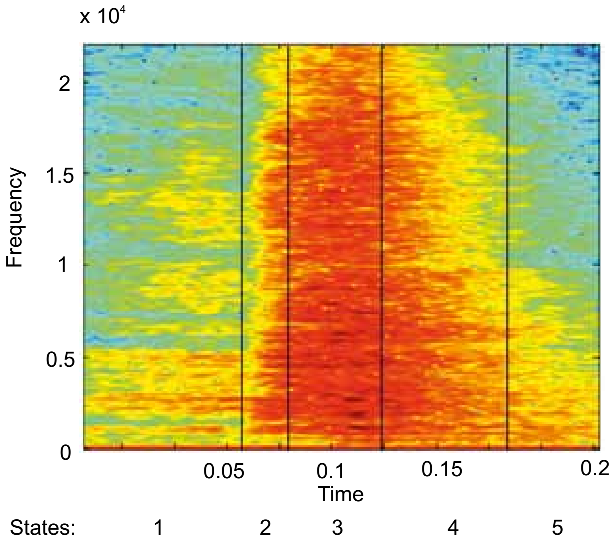

Figure 4:

Representation of five HMM states for a cough of a healthy pig elicited a by citric acid

Moreover, Figure 5 shows that not every cough has to be represented by the entire sequence of states. This depends on the differences of coughs within each cough type and adapts perfectly to these differences. For example, *Actinobacillus* coughs exist which have much higher frequencies at the beginning of the cough and more intensity than the cough shown in the Figure. This feature is modelled by a second alternative state, which is skipped for this cough.

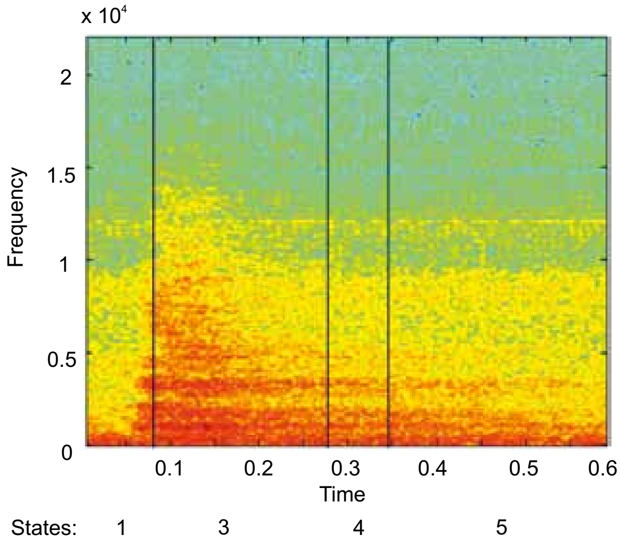

Figure 5:

Representation of the five states HMM for an unfiltered recording of *Actinobacillus* cough. Note: state two is skipped in this example. This is directly the desired effect of the modelled simple left-right HMM.

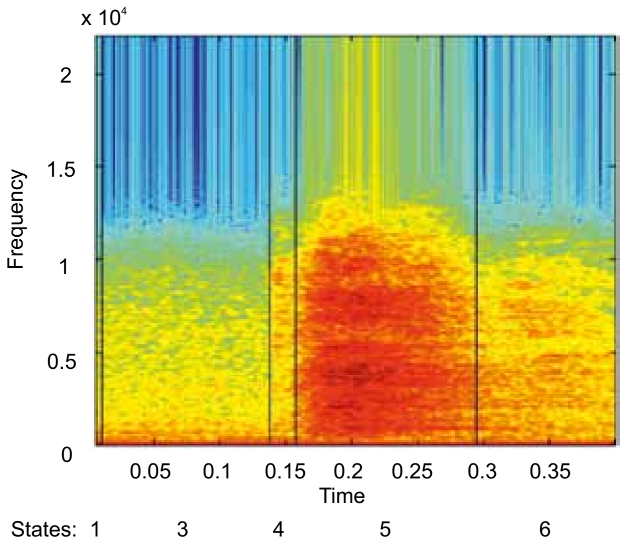

Figure 6:

Representation of a six states HMM for a filtered cough of a healthy pig elicited a by citric acid

Finally, short computation times are necessary for the usage of our software as an online recognition system. Of course the classification time always depends on the length of the cough type, the feature extraction methods and the classification method. All our experiments were run on a 2.4 GHz personal computer. Thus the computation time needed to classify a single cough (including feature extraction) is short enough, such that the classification can be performed in real time.

4 Discussion

Our results show that the classification with HMMs in combination with feature extraction methods from the area of speech recognition works fine. However, there are still several problems to be discussed:

- From speech recognition it is known, that LPC is sensitive to characteristics of the individual vocal tract (age, gender etc.) while especially MFCC and BFCC are not. This explains the better performance of the latter (s. Figure 2).
- The total recognition rate and state representation of the HMM show that data cleaning does not imply better results. This depends, on one hand, on our chosen filter method, and on the other on variances of the frequency bands. Having only a single fixed cut-off frequency for all cough types was shown to reduce the recognition rate, i.e., a simple low pass filter will sometimes also obviously destroy information important for correct classifications.
- While the chosen feature extraction methods work well, there are still two disadvantages. One problem is that these feature extraction methods are all based on frequency spectra which could be a disadvantage for fault-tolerant classification when extending the classification system. Furthermore the proposed feature extraction is complex to compute. Simpler time-based extraction methods might reach comparable classification accuracy with the advantage of lower computation time.
- A significant problem is also the small number of data available. More data (either recorded in an identical environment or coughs of the same type recorded in different environments) is needed to ensure accuracy, robustness and reliability.
- And finally, all experiments conducted here were performed on manually cut and labelled recordings of coughing events. However, to automatically monitor breeding facilities cough sounds have to be spotted within of a continuous sound stream, despite all of the ambient noise in a stable. To spot coughs in continuous recordings buried in noise will be the next problem to be addressed.

5 Conclusions

This paper explains how to classify coughing sounds of pigs using Hidden Markov Models. Focusing on *Pasteurella* and *Actinobacillus* infections, as compared to artificially induced coughs (e.g. induced by dust), we investigated the necessary data cleaning, feature extraction and model training. The results show that the classification with HMMs in combination with feature extraction methods from the area of speech recognition works excellently. Also, classification times even for such complex computations are satisfactory. Thus, this method is definitely acceptable for classifying pig coughs using a monitoring software.

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PM and ammonia in small group keeping – emissions and air quality in a German system for laying hens

Torsten Hinz*, Tatjana Winter*, Florian Zander*, and Stefan Linke*

Abstract

Cages for layers are banned in Germany since January 2010. Alternatives must be found e.g. floor keeping or aviaries. In Germany a new system, the so called small group keeping, is introduced. Groups of 28 to 60 hens are animal friendly housed with scraping area, separated nests for laying and perches for resting on a space of 890 cm² for each bird. With view to air quality inside and emission flows in comparison with other systems small group keeping has advantages for the stables investigated. Ammonia concentration is below 10 ppm (7.06 mg/m³) and respirable dust fraction below 4 mg/m³.

Keywords: Laying hens, keeping systems, small group, air quality, emissions, ammonia, PM

Staub und Ammoniak in der Kleingruppenhaltung – Emissionen und Luftgüte bei einem deutschen Haltungssystem für Legehennen

Zusammenfassung

Käfige für Legehennen sind seit Januar 2010 aus Deutschland verbannt. Alternativen müssen gefunden werden z. B. Bodenhaltung oder die Haltung in Volieren. In Deutschland wurde die sogenannte Kleingruppenhaltung eingeführt. Gruppen von 28 bis 60 Hennen leben tierfreundlich mit Scharrflächen, separaten Nestern zur Eiablage und Sitzstangen auf einer Fläche von 890 cm³ pro Henne. Hinsichtlich der Luftgüte im und den Emissionen aus dem Stall weist die Kleingruppenhaltung im Vergleich mit anderen Haltungssystemen Vorteile auf. Die Konzentrationen von Ammoniak liegen zumeist unterhalb von 10 ppm, die der alveolgängigen Staubfraktion unterhalb von 4 mg/m³.

Schlüsselworte: Legehennen, Haltungssysteme, Kleingruppe, Luftgüte, Emissionen, Ammoniak, PM

* Johann Heinrich von Thünen Institute (vTI), Institute of Agricultural Technology and Biosystems Engineering, Bundesallee 50, 38116 Braunschweig, Germany, torsten.hinz@vti.bund.de

Introduction

Two years before the entry into force of European regulations, cages for layers are banned in Germany since January 2010. Alternatives must be found e.g. floor keeping, aviaries or new systems. In Germany a new system, the so called small group keeping, was introduced since 2009 (TierschNutztV, 2009). With a decision of October12, 2010 by the Federal Constitutional Court the authorization for small group keeping systems for layers was cancelled due to formal reasons and March, 31 2012 is the deadline for amendment.

Keeping systems must follow the intentions of the society with high animal welfare requirements. Nevertheless protection of work and the environment cannot be neglected for evaluation and comparison of different systems. Groups of 28 to 60 hens are animal friendly housed with scraping area, separated nests for laying and perches for resting. In different studies recently and now the small group system is investigated and compared with floor keeping and an aviary with respect to air quality and emissions (Hinz et al., 2011; Hinz et al., 2010; Winter et al., 2009; Hinz et al., 2009). Concentration of ammonia and respirable dust (PM4) is measured inside the stable to estimate possible effects to men's and birds health and welfare. Emissions of ammonia, PM10 and PM2.5 are monitored to get an impression of possible environmental impacts.

The paper gives a description of the small group keeping system and a comprehensive view to the measuring procedures and results in examples. Finally the small group system is compared with two floor keepings and one aviary which have been investigated for three years by measurement.

Method and materials

In total over all studies measurements are carried out in different systems on commercial farms and research facilities. In two still running studies, eight stables – three on commercial farms and five experimental stables – are investigated. Project A compares four different types of layer husbandries: an aviary with integrated litter space (1); a floor keeping system with integrated litter space (2); a floor keeping system with outdoor access (3); and a small group keeping system (4). The system can keep layers in small groups of 28 to 60 birds. Because this system is a new development, project B studies influences of details given by different manufacturers of stables. The three manufacturers of the small group keeping system are marked as (4), (5) and (6). System parameters are given in Table 1. Two further stables of project B are not considered in this paper.

Table 1:
List of stables with stocking number, litter and manure management

keeping system	stocking	litter	manure management
1[1]	900	sand/wood shavings	manure belt, weekly
2[1]	8,000	wood shavings	storage inside
3[1]	3,000	without	storage
4[1, 2]	1,500	without	manure belt, weekly
5[2]	300	without	manure belt, weekly
6[2]	480	without	manure belt, weekly

[1] Project A
[2] Project B

In the centre of interest are the small group systems. Although there are creative possibilities of design and construction, the following principal requirements must be kept (TierschNutztV, 2009):

- Active area for each bird 890 cm²
- Additional scratching and sand bath area of 900 cm² per 10 birds
- Additional group nest area of 900 cm² per 10 birds
- Minimum area 25000 cm²
- Nests
- Perches

In practical use are mainly systems with stocking numbers of 40 to 60 birds. An example of a typical construction shows Figure 1.

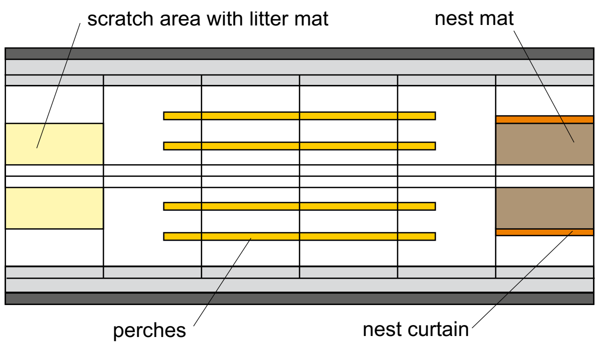

Figure 1:
A scheme of a typical small group system

In all cases the stables were equipped with manure belts and dryer. The dry manure is storage outside the stables. Also all stables are force ventilated and managed by a light programme. Some stable but not all are computer controlled (flow rate, light).

The measuring procedures and devices are nearly the same in all stables of the different studies.

To get an impression on the variations with time, daily courses are monitored. In one study additional spot measurements are carried out for one hour at noon to determine long term variation with the season and the age of birds. Table 2 shows the equipment to measure airborne concentrations and exhaust flow rate.

Table 2:
Measuring devices

contaminant	instrument	principle
ammonia	Innova 1302 multi gas monitor	opto acoustic
PM10, PM4, PM2.5	Grimm optical counter 1.105 and 1.108	light scattering
total dust	high volume sampler	gravimetry
air flow	Hoentzsch anemometer fan wheel	anemometry

The total dust sampler with pre-separator is used to collect dust for further analysis e.g. particle size analysis or imaging (Romann and Hinz, 2007).

Results and discussion

In the following examples of results are presented in two steps: first with the concern of air quality and secondly emission flows. Air quality is described by ammonia and PM4 concentration, the emissions by mass flow of ammonia, PM10 and PM2.5. PM10, PM2.5 and PM4 are calculated from the optical particle counter according to the definitions of US EPA and ISO 7708 respectively.

In contrast to ammonia, measurements of particle concentrations in gas flows must be done with the condition of an isokinetic probe, which means that flow in the exhaust opening and the sampler must be equal in magnitude and direction.

If emissions E from exhaust flows are determined by concentration c and air flow Q, c and Q must be measured simultaneously if both are fluctuating with respect to time:

$$E = \overline{c * Q} \neq \bar{c} * \bar{Q}$$

In both projects the conditions given above are regarded as accurately as possible.

Air quality

In Figure 2 a daily course of ammonia concentration is drawn. There are large differences between the systems of three producers, but the main message is that the level of concentration is very low and satisfies the wanted level of 10 ppm (7.06 mg/m³) and not only the prescribed limit of 20 ppm (14.12 mg/m³).

Figure 2 reflects the situation at one single day. Repetitions in different laying weeks (lw) are shown in Figure 3 for stable 5.

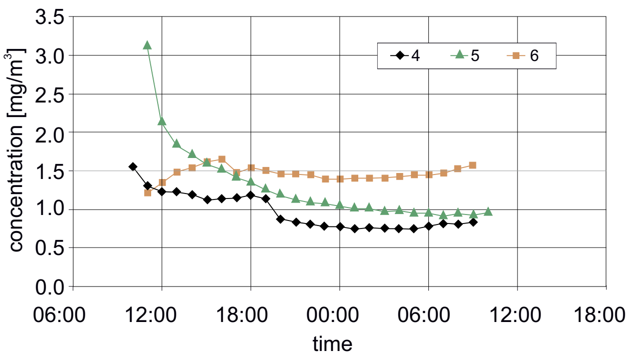

Figure 2:
Ammonia concentration in three small group keepings

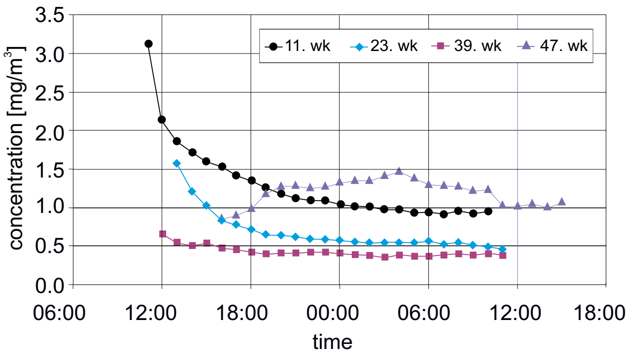

Figure 3:
Ammonia concentration, daily courses in stable 5 for different weeks

The situation is similar for the concentration of PM4, Figure 4 and 5.

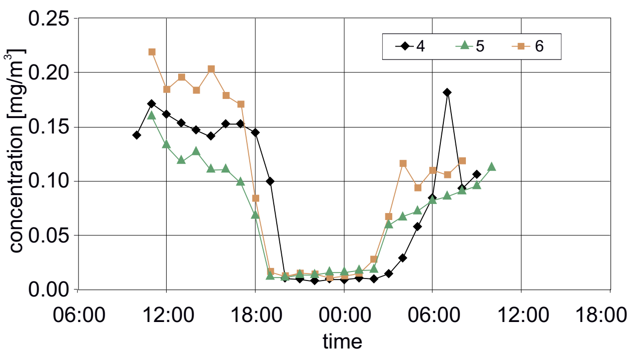

Figure 4:
PM4 concentration in 3 small group keepings

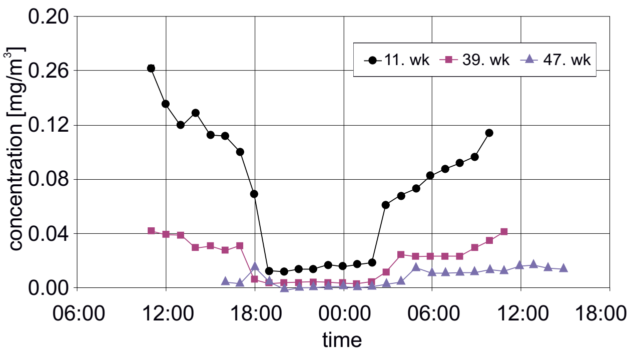

Figure 5:
PM4 concentration, daily courses in stable 5 for different weeks

In Figure 4 daily courses of PM4 concentration are drawn. There are large differences between the systems of three producers, but the main message is that the level of concentration is very low and satisfies very well the prescribed limit of 4 mg/m³.

Figure 4 reflects the situation at one single day. Repetitions are shown in Figure 5 for stable 5. It is clearly detectable that PM4 concentration is higher for younger birds than for the older ones.

The figures given above are based on 24h monitoring. To see possible seasonal influence the 1h spots of the ammonia concentration are used and demonstrated for stable 4 in Figure 6 in a box plot presentation.

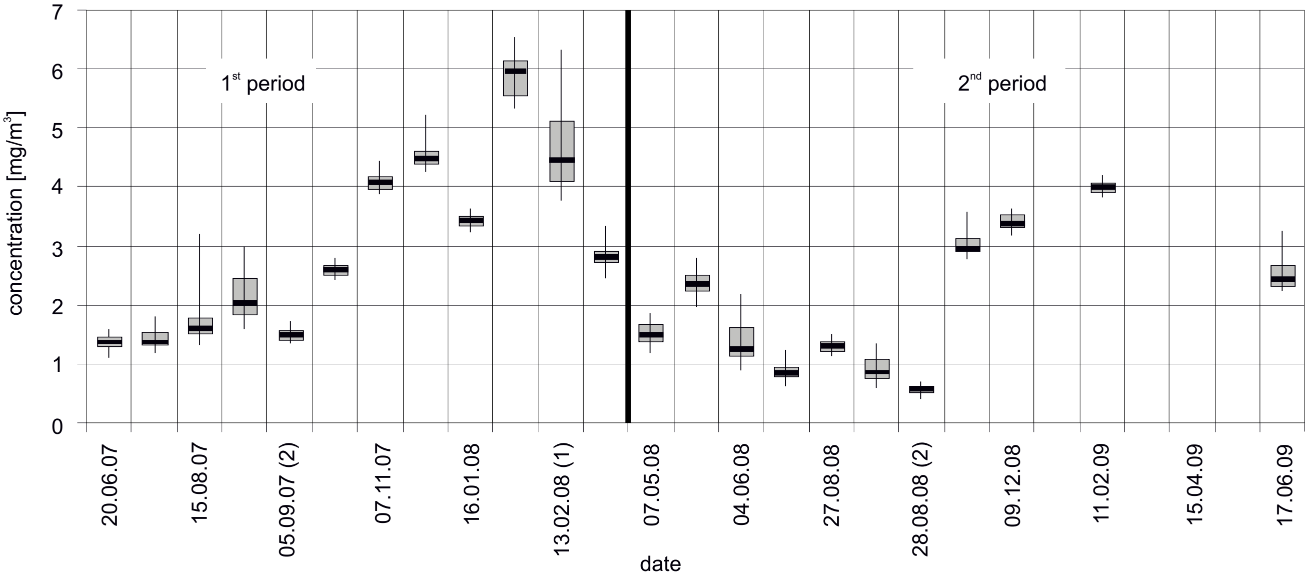

Figure 6:
Box and Whiskers plot of ammonia concentration in stable 4

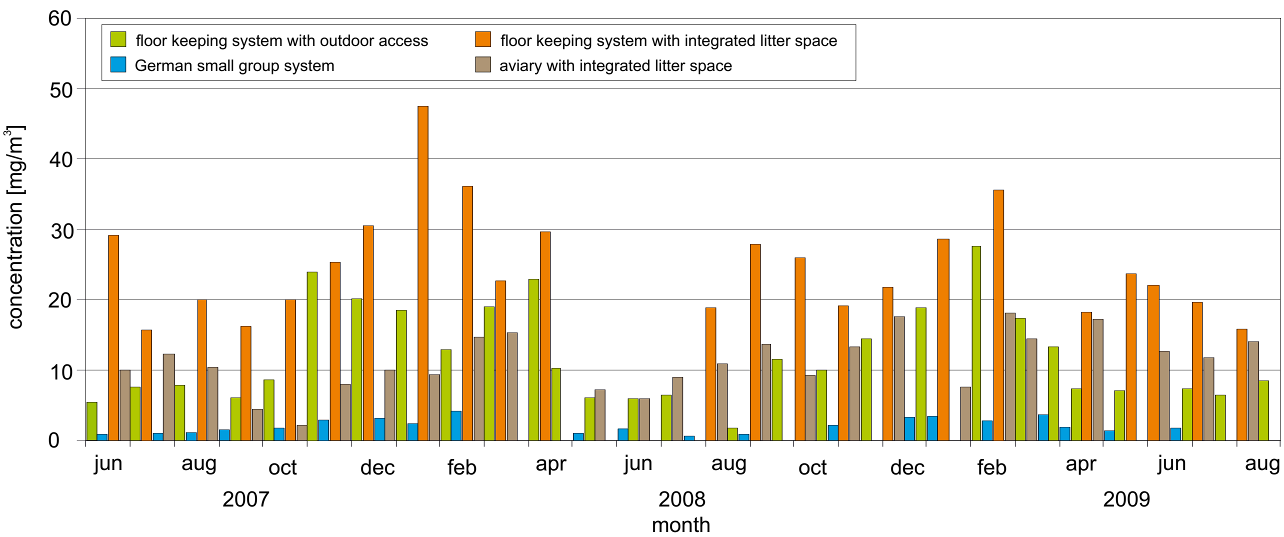

Figure 7:
Ammonia concentration for different types of alternative layer houses

The seasonable influence is obvious for both laying periods – concentration is higher in winter than in summer time, but nevertheless low over the year.

The same finding shows Figure 7 for all systems investigated in project A. But the main message is that in the small group keeping the lowest ammonia concentration is observed.

Emissions

With the typical air flows for all investigated stables of 700 to 10000 m³/h of the single stables emission flows range for 1h averages from <1 mg/(h*bird) to 180 mg/(h*bird) for ammonia and <1 mg/(h*bird) to more than 25 mg/(h*bird) for PM10.

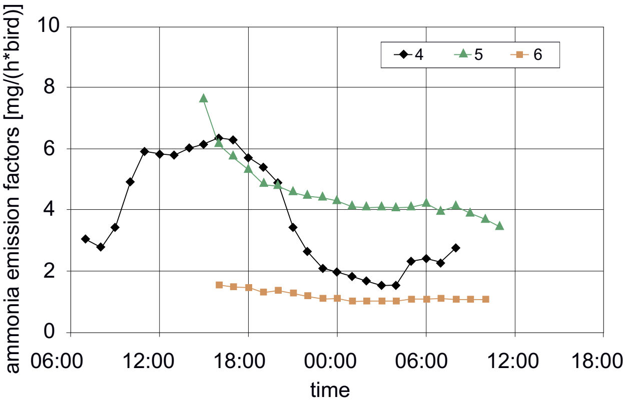

Figure 8:
Ammonia emission factors for the three small group keepings

Depending on the daily variations of concentration and air flow more or less typical courses of the emissions and emission factors are obtained. Ammonia concentrations are quite smooth (Winter et al., 2009). The time variations of emission factors follow the course of ventilation rate. Figure 8 shows this for ammonia emission factors of the three small group keepings. Ventilation rate is controlled by a stable computer in system 4 only.

As mentioned, emission is the product of concentration and air flow rate. If both are functions of time it becomes complicated to find short but representative spaces of time for comparison and evaluation of systems. System 4 in Figure 9 gives a first impression for ammonia. Figure 10 gives the emission factors of three different small group systems for PM10. It is obvious that day and night time must be distinguished.

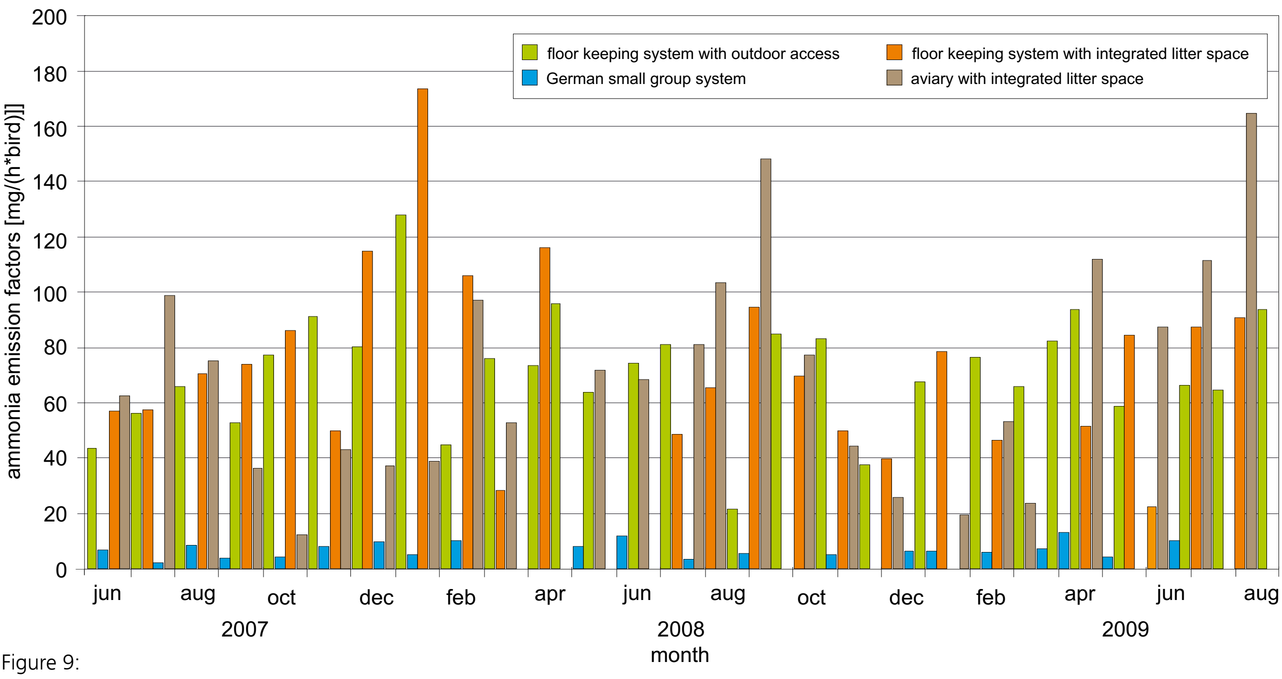

Figure 9:
Ammonia emission factors for different types of alternative layer houses

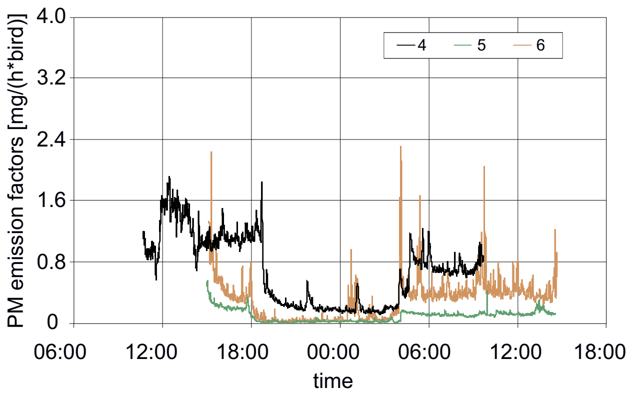

Figure 10:
PM10 emission factors for three different small group systems

Using again for comparison the description by 1 h noon spots, wide spans on different levels of emission factors are the result; cf. Table 3. The values in brackets are given in the EMEP EEA guidebook for inventory use.

Table 3:
Ammonia, PM10 and PM2.5 emission factors for the stable systems, 1h noon spots

stable	ammonia emission factor [mg/(h*bird)]	PM10 emission factor [mg/(h*bird)]	PM2.5 emission factor [mg/(h*bird)]
1	12 - 165	0.8 - 20	0.08 - 1.98
2	20 - 173	1.0 - 28	0.10 - 1.97
3	22 - 128 (20)	0.6 - 9.0 (9.45)	0.04 - 0.56 (1.95)
4	2.4 - 13.0	0.5 - 4.6 (2.0)	0.05 - 0.19 (0.22)
5	1.7 - 19.4	0.6 - 3.6 (2.0)	0.04 - 0.17 (0.22)
6	0.3 - 3.2	0.3 - 2.0 (2.0)	0.03 - 0.11 (0.22)

Summary and conclusion

A new German system for layers, the small group keeping system, is introduced. It is more animal friendly than conventional cages which are banned in Germany since January 01, 2010. A final decision on its future authorization must be made until March 31,2012.

In the centre of the study are concentration inside and emissions from different small group systems with view to ammonia and PM.

All measured values are very low with respect to wanted or given limits. Ammonia concentration did not exceed the limit of 10 ppm (7.06 mg/m³). PM4 levels are below 1 mg/m³ and far from the limit of 4 mg/m³.

The reasons for low concentration and emissions are given by no litter, the manure management with regard to ammonia and lighting strategy for PM emissions.

In comparison with other systems small group keeping has advantages with view to air quality and emissions.

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Phosphorus and trace metal distribution under confined cattle feeding operations in Southern Alberta

Frauke Godlinski*, Marc-Oliver Aust**, Greg Travis***, Xiying Hao***, Sören Thiele-Bruhn**, Tim A. McAllister***, and Peter Leinweber****

Abstract

Intensive beef cattle production in confined cattle feeding operations (CCFO) are characterized by accumulating layers of solid manure that cover the underlying mineral soil all year round. The extent to which nutrients and trace elements accumulate in the underlying soils is unknown but these present a potential risk to water sources as a result of surface run-off and leaching. Therefore, concentrations and depth distributions of phosphorus (P) and trace elements as typical marker compounds of manure affected environments were investigated in soil profiles of a research CCFO and compared to an unaffected grassland soil in the semi arid area of southern Alberta, Canada. Mean total P concentrations (TP) in the soil profiles were 384 mg kg^{-1} for the CCFO and 409 mg kg^{-1} for the grassland with only few significant differences between the soil profiles within each location and between the two locations. These differences could be explained by slight changes in the parent material. A sequential P fractionation revealed that most P occurred in the HCl fraction (> 51 % of TP), demonstrating strong binding of P to calcium and thus low mobility in these calcareous Dark Brown Chernozemic clay loam soils. There were no uniform enrichments and changes in the P fractions determined after nine years of CCFO operation. Similarly, there was no accumulation of the trace elements Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn in the soil profiles under the CCFO. In conclusion, under current feeding and management practices, there is a low risk of groundwater pollution through leaching from CCFOs under these semi-arid climate conditions.

Keywords: Phosphorus fractionation, phosphorus and metal accumulation

Zusammenfassung

Verteilung von Phosphor und Schwermetallen in Böden unterhalb intensiver Rinderhaltung im südlichen Alberta, Kanada

In Kanada ist intensive Rinderhaltung in offenen Mastieranlagen (Feedlots) eine gängige Produktionspraxis. In Feedlots verbleibt der anfallende Rindermist fast ganzjährig auf dem anstehenden verdichteten Mineralboden. Unklar ist inwieweit Nährstoffe und Schwermetalle wie Cd, Cr, Cu, Fe, Mn, Ni, Pb und Zn, in den darunterliegenden Böden akkumulieren und natürliche Wasserressourcen durch Austrag mit Oberflächenabfluss oder Sickerwasser gefährden. In dieser Studie wurden Konzentrationen und Verteilungen von Phosphor und Schwermetallen in Bodenprofilen unter einem experimentellen Feedlot und einem langjährig genutzten Graslandstandort ohne Beweidung untersucht. Die mittlere Konzentration an P-Total (TP) in Böden des Feedlots lag bei 384 mg kg^{-1} und bei 409 mg kg^{-1} unterhalb des Graslandes. Unterschiede in TP waren nur vereinzelt signifikant, sowohl beim Vergleich zwischen den Tiefenstufen innerhalb eines Bodenprofils, wie auch zwischen gleichen Tiefenstufen der Feedlot- und Graslandböden. Die wenigen signifikanten Unterschiede wurden mit Unterschieden im Ausgangsmaterial erklärt. Mittels sequentieller P Fraktionierung wurde der überwiegende P Anteil in der HCl-Fraktion nachgewiesen (> 51 % von TP), was die feste Bindung von P an Calcium und damit die geringe Mobilität in diesen tonigen Tschernosem-Braunerden hervorhebt. Es wurden keine gerichteten Anreicherungen und Veränderungen in den verschiedenen P Fraktionen wie auch den Schwermetallgehalten infolge neunjähriger Nutzung als Feedlot nachgewiesen. So ist zu schlussfolgern, dass in dieser semi-ariden Region und unter dem derzeitigen Futter- und Betriebsmanagement des Feedlots keine Auswaschung von Phosphor und Schwermetallen ins Grundwasser zu erwarten ist.

Schlüsselworte: Phosphor Fraktionen, Phosphor- und Schwermetallanreicherung

* Julius Kühn Institute (JKI), Federal Research Centre for Cultivated Plants, Institute for Crop and Soil Science, Bundesallee 50, 38116 Braunschweig, Germany; frauke.godlinski@jki.bund.de

** University of Trier, Soil Science Section, Behringstraße 21, 54286 Trier, Germany

*** Agriculture and Agri-Food Canada, Lethbridge Research Center, 5403 1st Avenue South, Lethbridge, Alberta, T1J 4B1, Canada

**** University of Rostock, Institute for Land Use, Justus-von-Liebig-Weg 6, 18059 Rostock, Germany

Introduction

Confined cattle feeding operations (CCFOs) are a common practice for beef production in Canada with the highest density occurring in southern Alberta. The construction and management of these CCFOs is regulated by the Alberta Agricultural Operation Practices Act guidelines. Modern operations are sited and managed according to these guidelines aiming to protect the environment by minimizing adverse impacts on the surrounding landscapes and watersheds (Olsen et al., 2005). The typical CCFOs structure includes the natural subsoil as the base, from which the topsoil was removed in the construction phase. During operation the subsoil is mostly covered by a black layer of mixed organic and mineral soil that forms in pens through cattle activity. This black layer is covered by manure which reaches up to 60 cm (Dantzman et al., 1983). The manure layer can be an important source of nutrient leaching and runoff (Miller et al., 2006; Olsen et al., 2005). In addition its physical properties influence nutrient transport by absorbing up to 25 mm of any precipitation before runoff occurs (Miller et al., 2008).

Previous studies focusing on the transport of nutrients, especially nitrate (NO_3^-) and phosphorus (P) (Schuman and McCalla, 1975), to the groundwater under such operations revealed contradicting results. Although increased concentrations of NO_3^- and salts in the soil profiles beneath CCFOs were found (Coote and Hore, 1979; Mielke et al., 1974), the risk of elevated P concentrations in the soils was low (Campbell and Racz, 1975; Coote and Hore, 1979). Studies investigating the nutrient enrichment under CCFOs built on loam soils tended to reveal only minimal leaching of NO_3^- from CCFO's operating for less than40 years and no leaching of P operating for up to 100 years (Vaillant et al., 2009; Zhu et al., 2004). By contrast, studies examining groundwater usually detected some nutrient enrichment under CCFOs (Miller et al., 2004). A study of five 25- to 35-year old CCFOs in central Saskatchewan focusing on nutrient concentration groundwater showed that 50 to 67 % of the groundwater samples had elevated solute concentrations due to the accumulation of manure (Maulé and Fonstad, 2000, 2002).

Solute transport from the manure was attributed to both matrix flow and preferential flow and contaminated shallow groundwater 20 m outside the CCFO (Miller et al., 2004). Also, in a three year operated CCFO the P concentrations in pen wells increased, whereas soil analyses indicated available P accumulations only down to 0.15 m soil depth, which may simply be a result of mechanical mixing by cattle (Olson et al., 2005). These discrepancies between the soil and groundwater data may be the result of possible preferential flow in the soil (Olson et al., 2005).

For predicting the mobility, bioavailability and potential of P transfer knowledge of the P distribution and availability in soils beneath manure with high P concentration is essential. A sequential fractionation allows a classification of the P in the soil in pools with varying availability for plants, leaching and the resulting environmental consequences (Thiessen and Moir, 1993; Negassa and Leinweber, 2009). This procedure separates P into plant-available (H_2O- and $NaHCO_3$-extractable; soil test P (STP)), Al- and Fe-hydroxide and oxide-associated (NaOH-extractable) and Ca-bound (HCl-extractable) forms (Hedley et al., 1982). Research has shown that high application rates of cattle manure on surrounding fields can cause an accumulation and change of P distribution in soil (Hao et al., 2008) and may increase concentrations of P in surface runoff and groundwater. This raises the question whether CCFOs with year round manure accumulation leads to changes in P fractions in the soil.

Besides organic matter, manure also contains major plant nutrients and trace elements, such as cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni), and zinc (Zn). With the exception of Pb, Cd and Cr, trace elements may be added as animal feed supplements to the cattle diet, in order to promote physiological processes and maintain animal health (Nicholson et al., 1999). Consequently, long-term application of such enriched manure to agriculture land increased the concentration of these metals in the soil (Benke et al., 2008; Thiele and Leinweber, 2001). This may also be the case for soils below CCFOs themselves as these are in contact with trace elements-enriched manure for long time periods. Depending mainly on the elements solubility, soil pH and binding capacity (Hesterberg, 1998) metals may be transported by leaching (Li and Shuman, 1997) or runoff (Moore et al., 1998) to water resources. Leaching of trace metals mostly occured in acidic and coarse textured soils (McBride, 1995), under neutral to alkaline soil conditions leaching is related to metal complexation with dissolved organic matter and preferential flow (Maeda and Bergstrom, 2000; McBride et al., 1997). Whereas the transport of nutrients may result in visible signs of eutrophication of water resources, the accumulation and transport of trace elements from soils beneath CCFOs and their possible enrichment in the food chain is relatively unknown and therefore should be taken into consideration when assessing the impact of CCFOs on the environment.

Therefore, in this study we determined the P and trace element concentration and the P distribution in manure and a soil of a Canadian research feeding operation and as a control in the subsoil of a natural grassland. We tested the hypothesis that after nine years of operation P and trace metals were translocated and accumulate in the soil underneath the manure and that this resulted in a change of P forms and therefore P availability even in deeper soil layers.

Material and Methods

Site description

This study was carried out at two research sites: (1) the research CCFO of the Agriculture and Agri-Food of Canada Lethbridge Research Centre in Lethbridge, AB, Canada (49° 43' N, 112° 48' W) and (2) a nearby grassland control. Both locations are of the same pedogenesis and soils classified as Dark Brown Chernozemic clay loam soils (Aridic Haplustolls – US Soil Taxonomy, Hao et al., 2003). The site of the CCFO consisted of lacustine material with about 1 m thickness over an oxidized till deposit (Olson et al., 2005).

The CCFO was constructed in 1995 to 1996 (Olson et al., 2005). During the construction phase the topsoil was, according to Alberta Agricultural Operation Practices Act guidelines, removed from the area, therefore all presented results will refer to the original subsoil. Clay material was used to construct the surface topography with an overall slope from south to north for drainage (Miller et al., 2003, 2004). The operation included 32 pens, each 14 m × 19.5 m. Each pen held 15 beef cattle (*Bos taurus*). All pens were bedded with barley straw and typically cleaned out by the end of August. During operation the cattle activity will create a typical black layer, a mixture of organic matter and clay. The grassland control was located approx. 1 km north of the CCFO. The site was reseeded to grass in 1930 and maintained without any fertilizer application or human activities until sampling. General soil characteristics can be found in Table 1. As stated by Aust et al. (2008) there were no significant differences in texture between the two sample sites.

The climate in this area is semiarid with an annual mean temperature of 6.4 °C between 1995 and 2005. The mean annual precipitation during this time was 409 mm, with a range from a maximum of 625 mm in 2005 to a minimum of 149 mm in 2001. Whereas in July 2005 only 13 mm precipitation was measured, in June 2005 the highest monthly precipitation of 269 mm occurred. In this month six rainfall events with > 22 mm per day and a maximum daily precipitation of 67 mm were recorded. All weather data were obtained from the meteorological station at the Lethbridge Research Centre at a distance of 0.7 km from the CCFO.

Soil and manure sampling

First, for comparison of P enrichment in the soil, samples from the CCFO and grassland were taken in July 2005 using a hydraulically powered truck mounted core tube (diameter 5 cm). From the grassland two sets of samples were taken to a depth of 110 cm in 10 cm increments. For comparison of the subsoil profiles, the topsoil samples from this location were excluded from further analysis; therefore, all results relate to subsoil depths. Samples were composited in increments of 0-10, 10-30, 30-60 and 60-90 cm. In the CCFO manure and soil samples were taken from locations with high manure density close to the feedbunk. Sampling ditches were created by removing the mixture of bedding and manure from the soil surface with a pitchfork on a square of approx. 30 cm × 30 cm. Three manure samples were taken above the mineral soil surface. Soil samples were taken in five different pens, in each pen three soil cores were obtained and samples were segmented in the depths 0-10, 10-30, 30-60 and 60-90 cm. As we tested the hypotheses that the nine year

Table 1:
Soil physical and chemical properties of the confined cattle feeding operation and the grassland in 2005

Depth	Sand	Clay	pH		TC		OC		TN	
cm	%				g kg^{-1}					
			Confined cattle feeding operation							
0-10	29	31	7.94 ± 0.03	A	18.32 ± 3.53		11.99 ± 1.27		1.43 ± 0.14	
10-30	30	29	7.81 ± 0.07	A	14.16 ± 3.35		6.70 ± 0.96	B	0.79 ± 0.13	B
30-60	37	30	7.97 ± 0.01	A	16.78 ± 2.61	B	4.83 ± 0.84	B	0.49 ± 0.09	B
60-90	33	29	8.02 ± 0.03		13.88 ± 2.45	B	3.62 ± 0.03	B	0.35 ± 0.01	B
			Grassland							
0-10	47	22	7.26 ± 0.09	B	15.99 ± 0.16		15.64 ± 0.20		1.64 ± 0.03	
10-30	34	27	7.44 ± 0.06	B	19.52 ± 0.04		19.27 ± 0.03	A	1.99 ± 0.00	A
30-60	30	27	7.74 ± 0.09	B	37.04 ± 1.26	A	14.22 ± 1.36	A	1.48 ± 0.05	A
60-90	36	25	7.95 ± 0.07		29.64 ± 0.27	A	6.00 ± 0.32	A	0.73 ± 0.01	A

For each soil depth, values in a column followed by different uppercase letters indicate significant ($P < 0.05$) location effects. Only significant differences are stated.
TC total carbon, OC organic carbon, TN total nitrogen

CCFO resulted in P enrichment in the subsoil through constant manure storage, total P and available P was determined in all pens. Since there was no difference between the pens, we focused further on the distribution of various P pools under such conditions. Therefore, as a second aspect, the changes over time caused by management were investigated. Therefore, samples from one pen, sampled in 1996, 1999 and 2005 were tested. The detailed sampling for the years 1996 and 1999 is described by Olsen et al. (2005). Briefly, soil samples were collected during the construction in March 1996 phase and during operation in August 1999. On the second sampling date the pens were empty of cattle and in the process of being cleaned of manure. Composite samples were prepared from three cores samples in depth increments of 0-15, 15-30, 30-60 and 60-90 cm. Since the annual cleaning resulted in a removal of the first cm of the original subsoil, it seems more suitable to only compare the first 10 cm in 2005 with the first 15 cm in the years 1996 and 1999. All samples taken in 1996, 1999 and 2005 were air dried, ground (< 2mm), and stored before analysis.

Soil and manure analysis

Available P and pH was measured in air dried and sieved < 2 mm soil and manure samples. The pH was measured in 0.01 M $CaCl_2$ at a solid to liquid ratio of 1:2.5 for soil and 1:10 for manure. Available P was determined with sodium bicarbonate (Olsen-P) according to (Olsen et al., 1954). Phosphorus concentrations in the extracting solutions were determined using a Technicon autoanalyzer (Technicon Industrial Systems, Tarrytown, NY). Soil texture was determined using the sieve-pipette-method according to DIN ISO 11277 (2002).

Soil and manure samples were further finely ground to < 0.150 mm for total carbon (TC) and total nitrogen (TN) analysis, determined by using dry combustion techniques with an automated elemental analyzer (Carlo Erba, Milan, Italy). Inorganic C was measured after acid treatment with a gas chromatograph using a modified method of Amundson et al., (1988) and organic C was calculated as the difference between total and inorganic C content (Table 1). Total P (TP) was measured by two methods. First, using the wet digestion method of Parkinson and Allen (1975). Briefly, 0.25 g of the soil sample was weighed into a digestion tube and digested at 360 °C for 1.5 h with concentrated H_2SO_4, Li_2SO_4, Se powder, and hydrogen peroxide. Phosphorus in digests was analyzed colorimetrically by the ammonium molybdate–ascorbic acid method (Murphy and Riley, 1962) using a Technicon AutoAnalyzer (Technicon Industrial Systems).

Secondly, TP was calculated as the sum of various P fractions; the P fractionation followed the method of Sui et al. (1999). Briefly, 1.5 g soil or 0.25 g manure (< 2 mm) were sequentially extracted as replicates with 30 mL of H_2O, 0.5M $NaHCO_3$, 0.1M NaOH and 1M HCl after 16 hours of shaking, centrifuge at 15,000 rpm and supernantant solution decanted. Afterwards the residues were digested with 18M H_2SO_4 (+ H_2O_2 and Li_2SO_4 + Se powder for digesting). The inorganic P (P_i) concentration in the extracts was directly analyzed colorimetrically by the ammonium molybdate-ascorbic acid method (Murphy and Riley, 1962) and the total P (P_t) concentration was measured after digestion with ammonium persulfate + 0.9M H_2SO_4 using a Technicon Autoanalyzer (Technicon Industrial Systems, Tarrytown, NY). The organic P (P_o) in the extract was calculated as the difference between P_t and P_i. Summarization of all P_t concentrations in extracts (H_2O, $NaHCO_3$, NaOH and HCl) and in the digested residual was the total P (TP) in the soil or manure. The sum of P_i in H_2O, $NaHCO_3$, NaOH and HCl is classified as total P_i, whereas the corresponding organic fractions are classified as P_o. The P_t H_2SO_4 is referred to as residual P (P_{res}).

Total concentrations of the elements Cd, Cr, Cu, Ni, Pb, Zn, Fe and Mn were determined after combustion of fresh soil at 950°C (Zeien and Brümmer, 1989). Briefly, 100 to 200 mg of combusted fine ground soil (< 0.125 mm) was weighed into 50 mL teflon tubes and 3 mL HNO_3 and 1 mL H_2O_2 were added. Fivefold samples were digested for 6 h at 170°C, filtered and diluted to 50 mL with double distilled water. The concentrations of trace metals in the resulting solution were determined using a Varian AA 240 DUO AAS (Varian, Germany).

Data handling and statistical analysis

Soil P fractions were statistically analyzed separately for the experimental research CCFO at three different sampling dates (1996, 1999 and 2005) and in the year 2005 at the two locations (CCFO and the grassland control). Trace elements in 2005 were also statistically analyzed for the two locations. The replicates were nested in location and year, so that the analysis was performed using a completely randomized design with PROC MIXED (SAS Institute Inc., 2005) with location, year and sampling depth, and their interaction treated as fixed effects. Tests of significant difference between the mean values were made using Fisher's protected LSD test and were considered significant only at $P < 0.05$.

Results and Discussion

Soil organic carbon and total nitrogen

While the TC contents were relatively constant in the CCFO profile, they showed a steep increase at 30-60 cm in the grassland profile (Table 1). However, OC was enriched only in the upper 10 cm of the CCFO. Below this depth OC varied in the range of 4 to 7 g kg^{-1}. This range of concentrations was observed in the grassland control profiles at 60-90 cm depth. Similar to OC the TN contents were smaller in the CCFO than in the grassland profile. The OC:TN ratio as indicators of organic matter changes in the profiles ranged from 8 to 10 (CCFO) and 10 to 8 (grassland) and indicated animal dung-derived N enrichments in the first 30 cm of the CCFO profile. If we compare the largest TN content under CCFO (1.43 g kg^{-1}) with the TN contents in the upper part of the grassland profile, than it is obvious that the dung accumulation in the CCFO did not result in any organic N enrichment. This can be explained by two processes: (i) arable soil management prior to the CCFO construction had reduced the native organic N content, and (ii) more excrement derived N was lost to the atmosphere in gaseous form than caused enrichments in soils. Reductions in TN contents of 0.6 g kg^{-1} following cultivation of the prairies were observed in a pair of native and cultivated soils from the Lethbridge region, and of 1.5 to 1.9 g kg^{-1} in soils from Saskatchewan (Leinweber et al., 2009). The above difference of 0.6 g kg^{-1} is comparable to the difference in TN between the grassland and the CCFO at 0-30 cm soil depth. Atmospheric N losses from the excrement can originate from NH_3 volatilization and denitrification. Major factors conducive to denitrification such as high organic matter, limited oxygen, due to compaction and alkaline pH (Tisdale et al., 1985) are combined in the CCFO (Table 1). Therefore, it is not surprising that no particular enrichment in TN was found in the CCFO soil profile

Total phosphorus in manure and soil

The TP concentration in the manure was 3097 mg kg^{-1} (Table 2), which is in the range of other studies on cattle manure (Turner and Leytem, 2004). The TP concentrations in the first 10 cm of the mineral soil beneath the manure were 384 in the CCFO and 391 mg kg^{-1} in the subsoil of the grassland. These values are typical for subsoils in this dark brown Chernozemic clay loam soils. In the CCFO profile the TP concentration varied between 356 and 409 mg kg^{-1}, with the highest concentration at a soil depth of 30-60 cm (Table 3). The TP distribution in the grassland soil was similar, but slightly higher values were observed (391 to 507 mg kg^{-1}). For both locations the pattern in the soil profile could be explained by the parent material with a change in soil texture and accumulation as calcium phosphate. Whereas in other areas high rainfall causes P leaching through the subsoil resulting in non-uniform dis-

Table 2:
Mean concentration (mg kg^{-1}) of various total P forms (P_t) and total P (TP) in the manure of the confined cattle feeding operation including the percentage of each fraction of TP (in parentheses) and the ratio of P_i/P_o per fraction (in parentheses)

H_2O P_t	$NaHCO_3$ P_t	NaOH P_t	HCl P_t	H_2SO_4 P_t	TP
788.6 (25.5)	694.4 (22.4)	615.5 (19.9)	826.1 (26.7)	172.5 (5.6)	3097.1
(78/22)	(80/20)	(28/72)	(41/59)		

Table 3:
Mean concentration (mg kg^{-1}) of various total P forms (P_t) and total P (TP) in the confined cattle feeding operation and the grassland control in 2005

Depth	H_2O P_t		$NaHCO_3$ P_t		NaOH P_t		HCl P_t		H_2SO_4 P_t		TP	
cm						mg kg^{-1}						
					Confined cattle feeding operation							
0-10	5.6	a	15.2	a	32.1	Ba	216.5	c	69.9	a	349.3	
10-30	5.4	ab	3.7	Bb	7.0	Bb	282.1	Abc	59.5	Bb	356.4	B
30-60	4.9	b	4.6	Bb	6.0	Bbc	349.9	a	43.3	Bc	408.7	
60-90	5.0	ab	4.2	b	4.5	Bc	318.7	Bab	42.0	Bc	374.4	B
					Grassland							
0-10	5.4		10.4		88.1	Ab	213.8	c	73.5	b	391.1	c
10-30	5.4		10.7	A	100.2	Aa	208.1	Bc	81.0	Aab	405.4	Ac
30-60	5.0		8.2	A	40.1	Ac	364.3	a	89.2	Aa	506.8	a
60-90	4.7		12.9		8.5	Ad	401.8	Aab	47.9	Ac	475.8	Ab

For each soil depth, P concentration in a column followed by different uppercase letters indicate significant ($P < 0.05$) location effects. For each location, P concentration in a column followed by different lowercase letters indicate significant ($P < 0.05$) soil depth effects. Only significant differences are stated.

Table 4:
Mean concentration (mg kg^{-1}) of various total P forms (P_t) and total P (TP) in the confined cattle feeding operation in the years 2005, 1999 and 1996

Depth	H_2O P_t		$NaHCO_3$ P_t		NaOH P_t		HCl P_t		H_2SO4 P_t		TP	
cm						mg kg^{-1}						
					Confined cattle feeding operation 2005							
0-10	5.6	ABa	15.2	Ba	32.1	Ba	216.5	Ac	69.9	a	349.3	
10-30	5.4	ab	3.7	Bb	7.0	Cb	282.1	bc	59.5	b	356.4	
30-60	4.9	b	4.6	Ab	6.0	bc	349.9	Aa	43.3	Cc	408.7	
60-90	5.0	ab	4.2	b	4.5	c	318.7	ab	42.0	c	374.4	
					Confined cattle feeding operation 1999							
0-10	6.5	Ba	27.0	Aa	62.2	Aa	249.4	Ab	65.3	a	410.4	a
10-30	5.6	b	4.6	Bb	20.3	Bb	255.7	b	57.5	b	343.7	b
30-60	5.5	b	3.4	Bb	7.9	c	247.7	Bb	68.5	Aa	333.0	b
60-90	5.5	b	3.7	b	4.0	c	313.9	a	44.8	c	371.9	ab
					Confined cattle feeding operation 1996							
0-10	4.9	A	9.4	Ca	31.7	Ba	221.3	Bc	68.6	a	336.0	b
10-30	5.2		6.7	Ab	24.7	Ab	261.0	bc	65.0	ab	362.6	ab
30-60	6.4		4.5	Ac	8.3	c	302.9	ABb	53.4	Bb	375.5	ab
60-90	5.2		4.3	c	5.5	c	351.2	a	37.4	c	403.7	a

For each soil depth, P concentration in a column followed by different uppercase letters indicate significant (*P* < 0.05) effects over years. For each location, P concentration in a column followed by different lowercase letters indicate significant (*P* < 0.05) soil depth effects. Only significant differences are stated.

tribution (Godlinski et al., 2004), this process is negligible in this semiarid area. Also, whereas TP concentrations in subsoils of cultivated soils increased after long-term heavy manure application (Eghball et al., 1996; James et al., 1996; Whalen and Chang, 2001), the uniform distribution of TP in the soil below the CCFO did not indicate a recent influence by tillage or uptake by plants. For the grassland, the long-term growth of perennial grass might have caused the partly significant differences in the soil profile as a result of microbial activity in the root zone.

During the period 1996 to 2005 no significant change in the TP concentration in the soil profile of the CCFO was observed (Table 4). Slightly different patterns in the profile were attributed to the mixing activity of the cattle, the cleaning process, the replacing of the clay layer and different sampling locations within the pen. Our results are in contrast to increases in P concentrations in CCFO soil profiles after 10 yrs on a fine sand loamy soil in Florida (Dantzmann et al., 1983), which may be explained by the coarser soil texture and the up to 3 times higher annual rainfall in Florida compared to the site of the present study.

Phosphorus fractions in manure and soil

The manure was characterized by an almost even distribution between the P fractions with 20 to 27 % of total P, except the H_2SO_4 (≤ 6 %) fraction (Table 2). Because nearly 50 % of the P is readily soluble (H_2O and $NaHCO_3$), there is a high potential for leaching or surface runoff after high rainfall events and pollution of water resources. In contrast to our findings, other researchers reported much greater proportions of available P, with P distributions of 67, 13, 5, and 5 % P from dairy (Dou et al., 2000) or 11, 43, 19 and 6 % P from cattle manures (Turner and Leytem, 2004) extracted by H_2O, $NaHCO_3$, NaOH, and HCl. Varying P concentration in bedding material, supplemented Ca to the animal feed to benefit reproductive health (Cooperband and Good, 2002), and different storage times are responsible for the wide range of P concentrations and distribution of P forms in manure. This is especially relevant in the HCl fraction.

In both of the calcareous dark brown chernozemic clay loam soils most of the P was determined in the HCl fraction (≤ 86 %), followed by the NaOH (≤ 24 %) > H_2SO_4 (≤ 20 %) > $NaHCO_3$ (≤ 4 %) > H_2O (≤ 2 %) fractions (Table 5). This distribution varied slightly between the two locations (Table 5) and over the years (Table 6), but in most cases this variation was not significant.

Whereas the proportion of the available P fractions (H_2O and $NaHCO_3$) and moderately labile fraction (NaOH) of TP decreased with soil depth, the proportion of the HCl fraction increased. This high proportion of Ca-bound P can be explained by the high calcium carbonate concentration in this glacial formed area (Table 1). While in the first 10 cm of the CCFO only 34.5 % are carbonate, it is > 52.7 % in the deeper layers. Similar results for high proportion of Ca-bound P were reported for soil profiles with pH > 7 from

Table 5:

Ratio of inorganic to organic P in each fraction and percentage of each fraction of total P (TP) for the confined cattle feeding operation and the grassland control in 2005

Depth	H_2O P		$NaHCO_3$ P		NaOH P		HCl P		H_2SO_4 P
cm	P_i/P_o	% of TP	P_i/P_o	% of TP	P_i/P_o	% of TP	P_i/P_o	% of TP	% of TP
				Confined cattle feeding operation					
0-10	10/90	1	61/39	4	23/77	8	95/5	68	18
10-30	8/92	2	100/0	1	20/80	2	97/3	79	17
30-60	9/91	1	100/0	1	43/57	1	89/11	86	11
60-90	16/84	1	100/0	1	60/40	1	92/8	85	11
				Grassland					
0-10	26/74	1	82/18	3	14/86	23	94/6	55	19
10-30	12/88	1	88/12	3	10/90	24	93/7	52	20
30-60	16/84	1	93/7	2	7/93	8	95/5	72	18
60-90	40/60	1	33/67	3	14/86	2	100/0	84	10

Table 6:

Ratio of inorganic to organic P in each fraction and percentage of each fraction of total P (TP) for the confined cattle feeding operation in the years 2005, 1999 and 1996

Depth	H_2O P		$NaHCO_3$ P		NaOH P		HCl P		H_2SO_4 P
cm	P_i/P_o	% of TP	P_i/P_o	% of TP	P_i/P_o	% of TP	P_i/P_o	% of TP	% of TP
				Confined cattle feeding operation 2005					
0-10	10/90	1	61/39	4	23/77	8	95/5	68	18
10-30	8/92	2	100/0	1	20/80	2	97/3	79	17
30-60	9/91	1	100/0	1	43/57	1	89/11	86	11
60-90	16/84	1	100/0	1	60/40	1	92/8	85	11
				Confined cattle feeding operation 1999					
0-10	12/88	2	100/0	7	28/72	15	95/5	61	16
10-30	13/87	2	57/43	1	14/86	6	96/4	74	17
30-60	12/88	2	96/4	1	15/85	2	100/0	74	21
60-90	28/72	1	100/0	1	25/75	1	94/6	84	12
				Confined cattle feeding operation 1996					
0-10	14/86	1	72/28	3	24/76	9	96/4	66	20
10-30	14/86	1	69/31	2	13/87	7	88/12	72	18
30-60	15/86	2	87/13	1	15/85	2	92/8	81	14
60-90	27/73	1	78/22	1	39/61	1	91/9	87	9

dairies in south Florida (Nair et al., 1995) and calcareous soils in Manitoba (Kashem et al., 2004).

The distribution of total P_i, P_o and P_{res} in the manure measured in 2005 was 54.2, 40.2 and 5.6 %, respectively, compared to the grassland soil with 57.1, 24.1 and 18.8 % and the CCFO soil with 69.3, 12.5 and 18.2 %. Higher proportion of P_o in the grassland than in the CCFO demonstrates a higher microbial activity, associated with biomass accumulation. This result agrees with data from a 13 yr-old feedlot on an alkaline sandy soil in Canada published by Campbell and Racz (1975), where the percentage of P_o and P_{res} decreased with depth, whereas P_i increased. This indicated that either P_i was more mobile than P_o and P_{res} or less P was incorporated into microbial biomass in the deeper soil horizons. Lower P_o concentrations under CCFOs were also reported by Campbell and Racz (1975), which were caused by a greater mineralization and depletion of organic P under anaerobic conditions.

The ratio of P_i and P_o suggested P_i dominance in manure for the H_2O and $NaHCO_3$ extracts, whereas P_o was dominant in the NaOH and HCl fraction (Table 2). These results revealed that, especially in the manure, significant concentrations of P_o can be found in the HCl fraction, which is in agreement with results for cattle manure and soil from He et al. (2006) as well as for swine and broiler samples (He et al., 2003; Dou et al., 2003). However, Turner and Leytem (2004), using ^{31}P NMR, determined only P_i in the HCl fraction of cattle manure. These discrepancies could be explained by the type and amount of bedding material and the Ca and Mg concentration in it. In comparison to the manure, the soil samples were classified by higher P_i than P_o ratios in the $NaHCO_3$ and HCl fraction, but higher P_o in the H_2O and NaOH fraction (Table 5 and 6). Values were similar for both locations, all soil depths and for all years for the CCFO. This indicates that neither P_o nor P_i of one of the mobile fractions was particularly leached and accumulated in deeper soil layers.

Our findings demonstrate that even though approximately 50 % of the P in the manure was determind in readily available form or in soluble fractions, the nine year management of the CCFO did not result in a significant P accumulation in the soil profile. This confirms results from long term CCFO's in southern Alberta (Sommerfeldt et al., 1973) and southern Minnesota (Zhu et al., 2004). Possible reasons are the compaction of the pen surface by cattle and machinery, which increased the bulk density from 1.70 to 2.18 g cm^{-3} within the first three years of usage (Olson et al., 2005), and scraping and removal of the enriched black mixed manure-soil layer which probably contained most P. Also, the semi-arid climate with mean annual precipitation around 400 mm reduces the P transport and transformation in the soil. Most precipitation will be absorbed in the manure or results in surface runoff after high rainfall events (Aust et al., 2008; Miller et al., 2008). Since the environmental pollution from this CCFO can be classified the application of this manure to surrounding agricultural land poses a risk of P enrichment in soil and groundwater due to leaching of labile fractions and wind erosion.

Trace metal concentrations within soil profiles

The total mean Cd concentrations at both locations (CCFO: 0.22 mg kg^{-1} and grassland: 0.36 mg kg^{-1}) were in the range 0.07 to 0.87 mg Cd kg^{-1}, reported for agriculturally used subsoils in Saskatchewan (Mermut et al., 1996; Krishnamurti et al., 1997). These authors reported that most of the Cd in the subsoil was precipitated as $CdCO_3$. Therefore, it is assumed that in the carbonaceous substrates with pH > 7 investigated in this study, Cd was also bound in carbonate form, making it less available for leaching. Other findings from a long-term manure experiment in the same Lethbridge area demonstrated higher values in the range 0.45 to 0.60 mg kg^{-1} (Benke et al., 2008), which is attributed to the long-term manure application (25 years), different origin of the manure and increased leaching through the soil because of irrigation.

The total Cr concentrations (mean 0.10 mg kg^{-1}) beneath the CCFO were lower than from the grassland and much lower than values published for subsoils in Saskatchewan (≤ 103 mg kg^{-1}; Mermut et al., 1996) and geochemical background concentration in soils across Canada (average 78 mg kg^{-1}; Rencz et al., 2006).

Mean Cu values ≤ 14 mg kg^{-1} were in the lower range of values across Canada with 5 to 50 mg kg^{-1} (McKeague and Wolynetz, 1980; Rencz et al., 2006) or in subsoils of heavily manured plots (Benke et al., 2008). Because of the basic soil pH (7-8) Cu occurs mostly in $CuCO_3$ form or adsorbed to Mn oxides, whereas the low Fe concentration in these soils plays a minor part for Cu sorption (Kabata-Pendias and Pendias, 2000).

The mean total Ni concentration in the soil profile of the CCFO (27.70 mg kg^{-1}) was slightly higher than in the grassland (24.86 mg kg^{-1}). However, both concentrations were in the range of soil and till values across Canada with a mean of 26.8 mg kg^{-1} (Rencz et al., 2006). The mobility of Ni in the soil is reduced by strong association to Mn as well as to organic matter. Although complexing ligands such as sulfate and organic acids reduce the sorption of Ni (Kabata-Pendias and Pendias, 2000), reduced leaching under these semi arid conditions prevents downward transport.

Both locations had similar Pb concentration with 7.30 mg kg^{-1}, which were lower than the average soil concentration (9.65 mg kg^{-1}) across Canada (Rencz et al., 2006) or ≤ 21 mg kg^{-1} in subsoils in Saskatchewan (Mermut et al., 1996).

Total Zn concentrations in the soil of the CCFO were lower with a mean of 46.22 mg kg^{-1} than in the grassland (63.02 mg kg^{-1}). The concentrations at both locations were in the range of Canadian subsoils from a 25 year manure experiment or from native prairies (Benke et al., 2008, Mermut et al., 1996). The Zn downward transport in the soils was reduced because of the possible Zn precipitation with carbonate (Usman et al., 2004) and fixation with inorganic compounds (Clemente et al., 2006; Walker et al., 2003).

Similar to Ni, the concentrations of Fe and Mn were higher in the soil profile below the CCFO (42.47 and 319.66 mg kg^{-1}) compared to the grassland soil (29.42 and 259.80 mg kg^{-1}). These differences can be explained by the high natural soil variability in this area, but also by input with the cattle manure as a result of natural concentrations in the animal feed or as additional supplements for animal health. Also, the higher total Fe and Mn concentrations in the soil of the CCFO did not affect the P distribution in the soil, especially the NaOH fraction. This leads to the conclusion that these two elements are not present in available form, which reduces their capability for P binding. The Fe concentrations in these soils correspond to < 16.5 % of the total Mn concentrations. Oxides and hydroxides of both elements are known for their high degree of association with trace elements (Kabata-Pendias and Pendias, 2000).

Overall, the trace element concentrations were not significantly different in the soil profile of the CCFO (Table 7). Even in the first 10 cm no accumulation occurred, because of removal of the black soil manure layer. Consequently, there was no potential for trace elements to move down the soil profile. Slightly higher mean concentrations, except for Fe, Mn and, Ni, were measured in the soil profile of the grassland (Table 7) but also with no significant changes, except for Mn, Ni and Zn in the profile. Both locations were mostly not significantly different in the trace element concentrations of each soil depth (Table 7).

Most trace elements are probably precipitated or in complex form with organic matter and/or P_o (Celi et al., 2000). This inhibits the mobility and therefore the availability for leaching in calcareous soils. Besides that, trace elements and phosphate in soils may influence the sorption of each other by competing for sorption sites or by influencing the surface charge (Thakur et al., 2006). Nevertheless, our results demonstrate a low risk for trace element transport under the CCFO.

Conclusions

The construction and management of the CCFO in the semi arid area of southern Alberta did not result in any undesired enrichment of organic matter or P in the soil profile. The annual cleaning process almost completely removed excrement, the black organic layer and the first cm of nutrient and trace metal enriched soil material and the high bulk density laid out during construction and enhanced through operation impeded leaching of solutes or colloidal matter into deeper parts of the soil profile. Low proportions of organic P as immobile Ca-bound P minimized P transport by matrix flow beneath the CCFO. Also the storage of manure in the pens did not significantly affect the metal concentrations in the underlying soil after nine years of intensive cattle use. In particular the high organic matter content of the manure probably favored the fixation within the first centimeters of the soil. Therefore, it can be concluded that the dry weather conditions and the alkaline pH in the underlying soils reduce transport of trace metals by leaching leading to a reduced risk of groundwater pollution. With correct implementation of the existing guidelines for CCFO the risk of groundwater pollution is relatively low under dry climate conditions, deep groundwater levels, compacted soils and soils with a high clay content. Consequently, the application of nutrient and trace metal enriched manure to surrounding fields needs to be regulated.

Table 7:
Total concentrations of trace elements in the confined cattle feeding operation and grassland in 2005

Depth	Cd		Cr		Cu	Ni		Pb		Zn		Fe	Mn	
cm	mg kg^{-1}													
	Confined cattle feeding operation													
0-10	0.17	b	0.09		10.79	29.52		6.05	b	53.09		26.84	291.2	
10-30	0.26	a	0.14		13.38	29.95		7.75	a	43.41		33.92	329.3	
30-60	0.19	Bab	0.07	B	11.88	26.87		6.25	Bb	52.58		47.66	314.9	
60-90	0.21	Bab	0.10		14.64	27.32	A	8.22	a	49.17		48.56	319.6	A
	Grassland													
0-10	0.30		0.17		11.59	27.15		6.13	b	70.52	a	25.40	282.5	ab
10-30	0.36		0.20		13.46	25.30		7.65	ab	67.07	ab	32.91	314.3	a
30-60	0.39	A	0.20	A	15.23	26.68		7.93	Aa	60.55	ab	27.99	251.5	ab
60-90	0.38	A	0.16		15.66	20.31	B	7.53	ab	53.95	b	31.38	190.9	Bb

For each soil depth, means (n = 5) in a column followed by different uppercase letters indicate significant (P<0.05) location effects. For each location, means (n = 5) in a column followed by different lowercase letters indicate significant (P < 0.05) soil depth effects. Only significant differences are stated.

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Catalytic conversion of renewables: Kinetic and mechanistic aspects of the gold-catalyzed liquid-phase glucose oxidation

Ulf Prüße, Sebastian Heidinger, and Christine Baatz *

Abstract

Among the studies about conversion of renewable resources, glucose oxidation to gluconic acid received very much attention in recent years. The present paper describes kinetic and mechanistic aspects of the liquid-phase glucose oxidation. Therefore a 0.3 % Au/Al_2O_3 catalyst prepared by the incipient wetness method was used. The reaction conditions were varied between 20 to 60 °C, pH 7 to 10, catalyst concentrations between 50 to 1200 mg l^{-1} and initial glucose concentrations between 10 to 1000 mmol l^{-1}. The concentration of dissolved oxygen was tracked for most experiments. An increasing activity was found with increasing pH value in the range between pH 7 and 10, and with increasing temperature in the range between 20 and 60 °C, whereas the selectivity to gluconic acid remained unchanged at > 99 % under these conditions. The activation energy was determined to be 53 kJ mol^{-1}. Analysis of the reaction orders with regard to glucose and oxygen leads to the conclusion that the Eley-Rideal model proposed by Beltrame et al. (2006) should be discarded for the gold-catalyzed glucose oxidation. Hydrogen peroxide is formed as by-product in glucose oxidation under oxygen atmosphere, whereas hydrogenated products are by-products under oxygen-free conditions. These observations have been explained by a modified oxidative dehydrogenation mechanism.

Keywords: conversion of renewables, gold catalyst, glucose oxidation, kinetics, mechanism

Zusammenfassung

Katalytische Konversion nachwachsender Rohstoffe: Kinetische und mechanistische Aspekte der goldkatalytisierten Glucoseoxidation in der Flüssigphase

Im Bereich der katalytischen Konversion nachwachsender Rohstoffe hat die goldkatalysierte Glucoseoxidation in den letzten Jahren besondere Aufmerksamkeit erlangt. Hier werden kinetische und mechanistische Aspekte der Glucoseoxidation anhand eines Aluminiumoxid-geträgerten 0,3 %igen Goldkatalysators, der nach der incipient wetness-Methode hergestellt wurde, beschrieben. Für die kinetischen Untersuchungen wurden Untersuchungen bei 20 bis 60 °C, pH 7 bis 10, einer Katalysatorkonzentration von 50 bis 1200 mg L^{-1} und einer Ausgangsglucosekonzentration von 10 bis 1000 mmol L^{-1} durchgeführt. Zusätzlich wurde die Gelöstauerstoffkonzentration bei zahlreichen Experimenten verfolgt. Mit steigendem pH-Wert und steigender Temperatur wurde eine Zunahme der Aktivität bei einer gleichbleibend hohen Selektivität von > 99 % festgestellt. Im untersuchten Temperaturbereich beträgt die scheinbare Aktivierungsenergie 53 KJ mol^{-1}. Die Analyse der Reaktionsordnungen in Bezug auf Glucose und Sauerstoff zeigt, dass ein Reaktionsverlauf der Glucoseoxidation nach dem Eley-Rideal-Modell, wie er von Beltrame et al. (2006) für diese Reaktion vorgeschlagen wurde, nicht zutreffend ist. Wasserstoffperoxid konnte als Nebenprodukt der Glucoseoxidation unter Sauerstoffatmosphäre nachgewiesen werden, wohingegen unter Sauerstoffausschluss auch hydrierte Produkte gebildet werden. Durch einen modifizierten Mechanismus der oxidativen Dehydrogenierung konnten beide Beobachtungen erklärt werden.

Schlüsselworte: Katalytische Konversion nachwachsender Rohstoffe, Goldkatalysator, Glucoseoxidation, Kinetik, Mechanismus

* Johann Heinrich von Thünen Institute (vTI), Federal Research Institute for Rural Areas, Forestry and Fisheries, Institute of Agricultural Technology and Biosystems Engineering, Bundesallee 50, 38116 Braunschweig, Germany; Corresponding author: Tel.: +49 531 596 4270; Fax: +49 531 596 4199. E-mail address: ulf.pruesse@vti.bund.de

1. Introduction

The conversion of renewable resources to valuable products of the chemical industry is an attractive way to save fossile resources and CO_2 emissions endangering global climate. Among the biomass carbohydrates glucose is the most abundant bio-feedstock for this purpose. In this regard, the metal-catalyzed liquid-phase oxidation of glucose to gluconic acid by gold nanoparticles has received much attention during very recent years. As first described by Biella et al. (2002), gold nanoparticles in the range of 2 to 5 nm supported on carbon show a much higher activity under mild reaction conditions than the conventional platinum and palladium based catalysts applied so far for this reaction. Further on, the Au/C catalyst exhibits an outstanding selectivity of 100 % towards gluconic acid, a fine chemical with an annual worldwide production capacity of about 100,000 tons (Lichtenthaler, 2006), currently exclusively produced by biocatalytic glucose oxidation.

The majority of the studies on gold-catalyzed glucose oxidation used carbon-supported gold nanoparticles originating from preformed gold sols (Biella et al., 2002; Önal et al., 2004; Comotti et al., 2005; Comotti et al., 2006a and b), polymer-stabilized gold colloids (Mirescu and Prüße, 2006), glucose-stabilized gold sols (Beltrame et al., 2006) or gold colloids in "naked" form (Comotti et al., 2004; Comotti et al., 2006c). In some of these studies (Beltrame et al., 2006; Comotti et al., 2004; Comotti et al., 2006b) the activity of the gold nanoparticles have been described as lower but comparable to the activity of the enzyme used in the technical processes for the production of gluconic acid (Beltrame et al., 2004). Taking into account the outstanding almost 100 % selectivity of the gold nanoparticles, which saves additional purification expenses, an industrial gold-catalyzed glucose oxidation process seems to be within range. Unfortunately, gold colloids, as well as carbon-supported gold nanoparticles derived from preformed sols, do not fulfil the major requirement for a catalyst to be used in an industrial process: a high long-term stability. The naked colloids agglomerate after a few minutes so that complete conversion can not be reached (Comotti et al., 2006c), and a chitosan-stabilized colloid precipitated in flakes has been described to lose about 90 % of its initial activity after eight repeated batches (Mirescu and Prüße, 2006). Also the carbon-supported gold nanoparticles originating from preformed sols do not perform much better as they lose about 50 % or 60 % of their initial activity within 4 or 5 repeated batches, respectively (Biella et al., 2002; Comotti et al., 2006b).

However, highly active, almost 100 % selective and long-term stable gold catalysts for the liquid-phase carbohydrate oxidation can be obtained by using metal oxides as support material, e.g. Al_2O_3 or TiO_2 prepared either by deposition-precipitation with NaOH or urea or by the incipient wetness method (Baatz and Prüße, 2007; Baatz et al., 2007; Mirescu and Prüße, 2007; Mirescu et al., 2007; Thielecke et al., 2007a and b). These catalysts have been used for the oxidation of glucose and various other aldoses to their corresponding aldonic acids in repeated batch experiments as well as partially under continuous-flow conditions. No matter which catalyst or reaction conditions were applied, the metal oxide-supported gold catalysts always showed a high activity, nearly 100 % selectivity and, as no activity and selectivity loss occurred, a high long-term stablility. Hence, gold nanoparticles supported on metal oxides fulfil all necessary requirements for their application in an industrial carbohydrate oxidation process to produce various aldonic acids, e.g. gluconic acid.

Knowledge about the reaction kinetics of the gold-catalyzed glucose oxidation is very important with regard to an up-scaling of the process to industrial scale. Thus far, only few studies about glucose oxidation reaction kinetics with gold catalysts are available (Beltrame et al., 2006; Önal et al., 2004). In one study carbon-supported gold nanoparticles derived from preformed gold sols have been used (Önal et al., 2004) whereas glucose-stabilized gold colloids have been used in the other one (Beltrame et al., 2006).

Surprisingly, contrary results have been obtained in these two studies. Önal et al. (2006) reported that the reaction follows the Langmuir-Hinshelwood model in which both glucose and oxygen are adsorbed. They found only a negligible increase of the initial reaction rate with rising initial glucose concentration, but a distinct selectivity decrease. Beside glucose isomerisation products such as mannose and fructose, and degradation products such as the oxygenated C3-bodies glycerolaldehyde or dihydroxyacetone, also the hydrogenated product sorbitol, have been found. The latter product gives strong evidence that the reaction follows the oxidative dehydrogenation mechanism well known for the liquid-phase noble metal-catalyzed oxidation of alcohols and aldehydes (Besson and Gallezot, 2001a and b; Gallezot and Besson, 1995; Mallat and Baiker, 1994).

In contrast to these findings, Beltrame et al. (2006) reported about an increase of the initial reaction rate with rising initial glucose concentration tending to an asymptote at higher glucose concentration. This result, together with an experimentally derived reaction order of 1 for oxygen, has led to the assumption that the glucose oxidation follows the Eley-Rideal model in which dissolved oxygen reacts from the liquid phase with glucose adsorbed at the catalyst surface. However, the Eley-Rideal model suggested by Beltrame et al. (2006) is in contradiction to another study of the same group. Comotti et al. (2006c) proposed a new reaction mechanism for glucose oxidation, which is different from the oxidative dehydrogenation mechanism, but able to explain the experimentally determined intermediate formation of hydrogen peroxide. According to this mechanism both glucose and oxygen are adsorbed at the catalyst surface at the same time.

The contrary kinetic models reported in the two studies are based on the dependence of the reaction rate on the initial glucose concentration, which has been studied only in a small range of glucose concentrations, i.e., 100 to 450 mmol l^{-1} by Önal et al. (2004) and 50 to 500 mmol l^{-1} by Beltrame et al. (2006). It has already been pointed out that 'the experimental evidence is hardly sufficient to support that differentiation' (Bond et al., 2006).

In the present study, reaction kinetics of the liquid-phase glucose oxidation using an 0.3 % Au/Al_2O_3 catalyst at 1 bar oxygen pressure is examined. The activity and selectivity of the catalyst has been further studied in dependence of the catalyst concentration, pH value, temperature and initial glucose concentration from 10 mmol l^{-1} up to 1000 mmol l^{-1}. This larger concentration span should give more significant results compared to the other two kinetic studies. Particular care has been taken to avoid oxygen mass transfer limitation by monitoring the dissolved oxygen concentration during the course of reaction whenever possible. Reaction orders have been analyzed for glucose and oxygen, and the activation energy is reported. Finally, basing on own experiments and literature data, a modified oxidative dehydrogenation mechanism for the gold-catalyzed glucose oxidation is proposed which takes the formation of hydrogen peroxide into account.

2. Experimental

2.1 Chemicals

Powdered mesoporous aluminium oxide type Puralox KR-90 from Sasol, Germany, (BET surface area = 88 m^2 g^{-1}, pore volume = 0.63 ml g^{-1}, mean particle size = 40 µm) was used as support material and $HAuCl_4 \cdot xH_2O$ (gold content 50 wt %) from Chempur, Germany, as the gold precursor. D(+)-glucose monohydrate (for biochemical use) from Fluka, Germany, and KOH (purity 86 %) from Fluka, Germany, were used as supplied. Technical oxygen (purity 99.95 %) from Linde, Germany, was used as an oxidant without further purification.

2.2 Catalyst preparation

The gold catalyst used in the present study was prepared by the incipient wetness method according to the following procedure: A volume of an acidic aqueous solution of $HAuCl_4$ in the desired concentration, which corresponds to the pore volume of the alumina support, was added drop-wise within 15 min to the support material during intensive mixing in a mortar. At the end of this procedure the catalyst precursor becomes slightly wet. After the precursor was dried overnight at 75 °C in air, it was reduced for 2 h at 250 °C in a 10 vol% H_2/90 vol% N_2 stream. ICP-AES analysis confirmed a gold content of 0.3 %.

2.3 Glucose oxidation procedure

Glucose oxidation was carried out in a thermostatted glass reactor (total volume 600 ml, initial reaction volume 500 ml) equipped with a reflux condenser, a pH electrode and a burette for base dosage, a glass frit for the oxygen supply, an oxygen electrode, a gas outlet and a magnetic stirrer which operated at 900 rpm.

Prior to the start of the reaction the desired catalyst amount was suspended in 450 ml of deionized water at the desired pH value inside the reactor. This suspension was thermostatted until the reaction temperature was reached, while oxygen at atmospheric pressure was bubbled through the suspension at a flow rate of 500 ml min^{-1} to saturate the suspension with dissolved oxygen. A reaction was started by first adding the desired amount of glucose dissolved in 30 ml of deionized water thermostatted at the reaction temperature and afterwards 20 ml of deionized water used for rinsing to ensure that all glucose had been added to the reactor. At initial glucose concentrations of 500 mmol l^{-1} and 1000 mmol l^{-1}, the catalyst was suspended in a smaller amount of water, as more water was needed to dissolve the larger amounts of glucose.

During the reaction the oxygen supply was maintained at the same flow rate and the pH value was kept constant with an automatic titrator (TitroLine alpha, Schott, Germany) by adding aqueous KOH in concentrations between 0.25 mol l^{-1} and 10 mol l^{-1} depending on the initial glucose concentration used. In different sets of experiments, one of the parameters: catalyst concentration, pH value, temperature or initial glucose concentration was varied, while the others, unless otherwise stated, were fixed at the standard reaction conditions, i.e., 140 mg l^{-1} catalyst concentration, pH 9, 40 °C, 100 mmol l^{-1} initial glucose concentration. During reaction course, the amount of added KOH and, when possible (see Section 2.4), the concentration of dissolved oxygen were monitored. All reactions were carried out until a conversion > 99 % was reached. Conversion and selectivity were checked with a HPLC system as previously reported (Baatz et al., 2007; Mirescu and Prüße, 2007).

2.4 Dissolved oxygen

During the course of all reactions carried out up to 40 °C, which marks the highest application temperature of the oxygen measurement system, the concentration of dissolved oxygen was tracked by an oxygen electrode (CellOx 325, WTW, Germany) in combination with a measuring instrument (Oxi 340i, WTW, Germany). All measured oxygen concentrations were normalized with regard to the highest oxygen concentration occurring during each reaction course (always after complete glucose conversion) and are reported as percentage of the maximum oxygen solubility at the end of the reaction.

The solubility of oxygen in the reaction suspension depends on the temperature, the glucose concentration and the salinity of the suspension. As displayed in Table 1, the influence of the temperature on the oxygen solubility is higher than the influence of the glucose concentration. The oxygen solubility values reported in Table 1 were calculated by using Henry constants interpolated from Henry constants for aqueous glucose solutions reported in the literature (Rischbieter et al., 1996) and assuming that the temperature dependence of oxygen solubility in aqueous glucose solutions corresponds to that of oxygen in water (Radtke et al., 1998).

Table 1:

Calculated concentrations of dissolved oxygen in the reaction suspension at 1 bar oxygen pressure in dependence of the initial glucose concentration and temperature

$c_{0,\ glucose}$ mmol l^{-1}	Temperature °C	c_{oxygen} mmol l^{-1}
10	40	0.972
50	40	0.966
100	40	0.956
250	40	0.925
500	40	0.872
1000	40	0.766
100	20	1.350
100	30	1.122
100	40	0.956
100	50	0.825
100	60	0.728

If the concentration of dissolved oxygen is to be monitored during glucose oxidation, a problem emerges. The decreasing glucose concentration with proceeding conversion leads to an increasing oxygen solubility while the increasing salinity caused by the formation of the reaction product potassium gluconate leads to a decreasing solubility (Radtke et al., 1998). Both effects become significant at higher initial glucose concentrations, i.e., 500 mmol l^{-1} and 1000 mmol l^{-1}, and may lead to an estimated error with regard to the reported oxygen values of about 10 %.

2.5 Evaluation of catalytic activity

The gluconate versus time plots were derived from the rate of KOH addition. As, with HPLC analysis, a conversion and selectivity of > 99 % had been determined for all experiments reported here, the KOH addition rate directly corresponded to the glucose conversion and gluconate formation. A typical gluconate versus time plot is shown in Figure 1, in which, after a short induction period, a linear increase of the gluconate concentration up to about 80 % conversion can be noted before the reaction rate subsequently decreases towards complete conversion. As indicated by the fit line in Figure 1, the linear part of the curve was used to calculate the activity from the slope of the fit line. Further on, the activity is referred to the gold content of the catalyst, so that it is given in terms of mmol of produced gluconate per minute and per gram gold, i.e., mmol min^{-1} g_{Au}^{-1}.

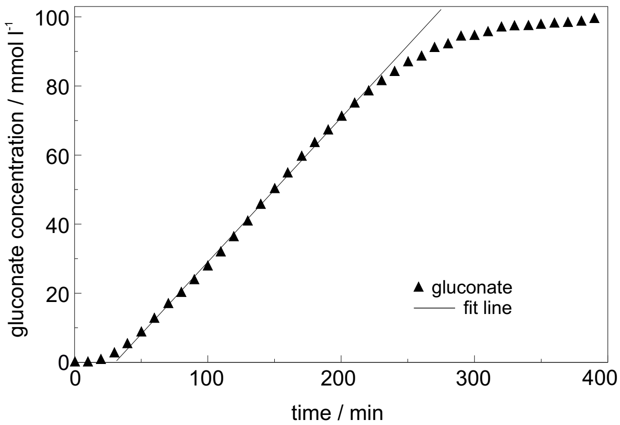

Figure 1:

Typical gluconate versus time plot. The slope of the fit line in the linear part of the curve is used to calculate the activity of the catalyst. Reaction conditions: ccatalyst = 140 mg l^{-1}, $c_{0,\ glucose}$ = 100 mmol l^{-1}, 40 °C, pH 9.

2.6 Analysis of hydrogen peroxide

Hydrogen peroxide was analysed according to the procedure described by Comotti et al. (2006c). Therefore, the pH of the periodically withdrawn 10 ml samples was adjusted to 1.8 by adding 0.5 mol l^{-1} H_2SO_4. After addition of 0.5 ml $MnSO_4$ solution (c = 1 mmol l^{-1}) the samples were titrated with 20 mmol l^{-1} $KMnO_4$ solution.

2.7 Glucose oxidation under oxygen-free conditions

For this reaction the same equipment was used as described in 2.3. For the reaction, 100 mmol l^{-1} Glucose was first stirred with 10,000 mg l^{-1} catalyst at 40 °C at pH 9 for 24 h. After 24 h, the pH was adjusted to 10.5. These conditions were maintained for another 60 h so that the whole reaction lasted 94 h. The pH value was kept constant at all times by titrating 2.5 mol l^{-1} KOH. Instead of oxygen, nitrogen (purity 99.999 %) was bubbled permanently through the suspension at a flow rate of 50 ml min^{-1} in order to secure oxygen-free conditions.

Analysis of the reaction mixture after 94 h was performed as described in section 2.3. The results were confirmed by an additional analysis carried out by Südzucker AG.

3. Results and discussion

For an analysis of reaction kinetics, mass transfer limitations have to be excluded. To exclude pore diffusion, a finely powdered catalyst support was used and a low gold loading was adjusted to the catalyst. To exclude external mass transfer limitations a high stirring rate of 900 rpm was applied. As oxygen, due to its low solubility, is the deficit compound in glucose oxidation (see Table 1) a sufficient concentration of dissolved oxygen during the reaction course has to be ensured by adjusting a proper catalyst concentration.

3.1 Influence of catalyst concentration

To figure out the influence of the catalyst concentration on the apparent reaction rate and the amount of dissolved oxygen during the reaction course, catalyst concentrations from 50 to 1200 mg l^{-1} were used for glucose oxidation under otherwise standard reaction conditions (see Section 2.3).

The course of produced gluconate and the normalized oxygen concentration versus time are displayed in Figures 2 A and B for two catalyst concentrations. At the lowest applied catalyst concentration, i.e., 50 mg l^{-1}, which is shown in Figure 2A, the concentration of dissolved oxygen during the reaction course remains almost constant at the saturation level. Thus, even at the highest reaction rate during this run, the rate of oxygen dissolution is higher than the rate at which oxygen is consumed by the reaction. In contrast, the second highest catalyst concentration applied here, i.e., 800 mg l^{-1}, leads to a dramatic decrease of the normalized oxygen concentration to below 10 % immediately after the reaction has started. After about 50 % glucose conversion, the oxygen concentration slowly starts to increase. A value of 50 % dissolved oxygen is reached at 90 % glucose conversion, and the saturation value of 100 % is not attained before complete glucose conversion. Needless to say that such a pronounced decrease in dissolved oxygen significantly influences the activity of the catalyst.

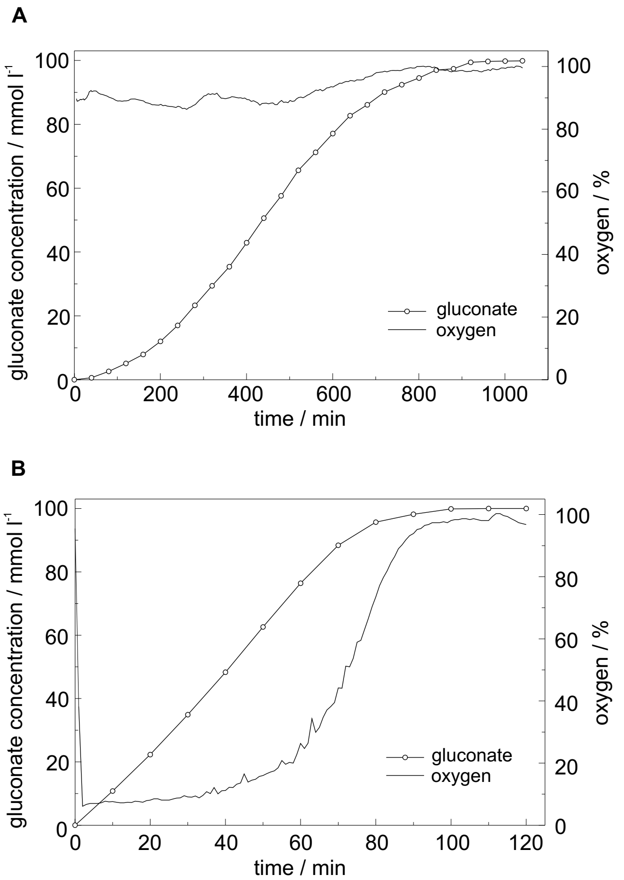

Figure 2:

Gluconate and normalized oxygen concentration versus time plots for a catalyst concentration of A: 50 mg l^{-1} and B: 800 mg l^{-1}. Other reaction conditions: $c_{0,\ glucose}$ = 100 mmol l^{-1}, 40 °C, pH 9.

The reaction rate of glucose oxidation in dependence of the applied catalyst concentration is depicted in Figure 3. As expected, the reaction rate tends to be an asymptote at high catalyst concentration when an external mass transfer limitation becomes apparent, whereas a linear increase, i.e., no external mass transfer limitation, can be observed up to a catalyst concentration of about 200 mg l^{-1}. For some of the applied catalyst concentrations the course of the normalized oxygen concentration versus glucose conversion is additionally displayed in Figure 4. It can clearly be noted that the oxygen concentration drops considerably with rising catalyst concentration. Lowest oxygen concentrations at a single catalyst concentration can be found at between 10 % and 50 % glucose conversion, when the observed reaction rate is highest for all catalyst concentrations. At a catalyst concentration of 140 mg l^{-1}, a concentration at which the results shown in Figure 3 confirm no mass transfer limitation, the oxygen concentration over the whole glucose conversion drops down to 60 % at maximum (Figure 4). At the higher catalyst concentration of 400 mg l^{-1}, a concentration at which the results shown in Figure 3 clearly indicate beginning mass transfer limitations, the oxygen concentration drops down to about 40 % during the first 50 % of glucose conversion (Figure 4). It can thus be concluded that the normalized oxygen concentration should not fall below 50 % at any time during the reaction course in order to avoid oxygen mass transfer limitations.

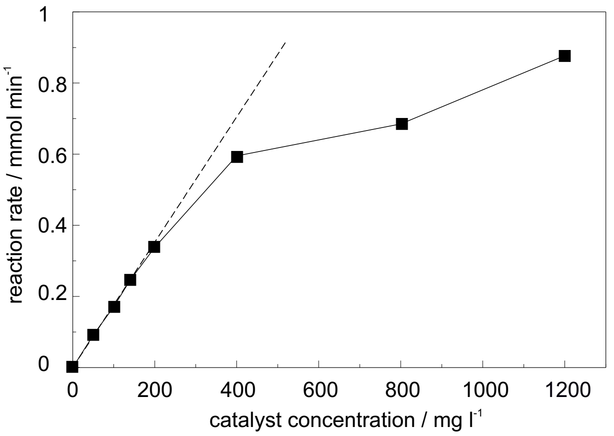

Figure 3:

Influence of the applied catalyst concentration on the apparent reaction rate. The dashed line indicates the reaction rate without external oxygen mass transfer limitation. Other reaction conditions: $c_{0,\ glucose}$ = 100 mmol l^{-1}, 40 °C, pH 9.

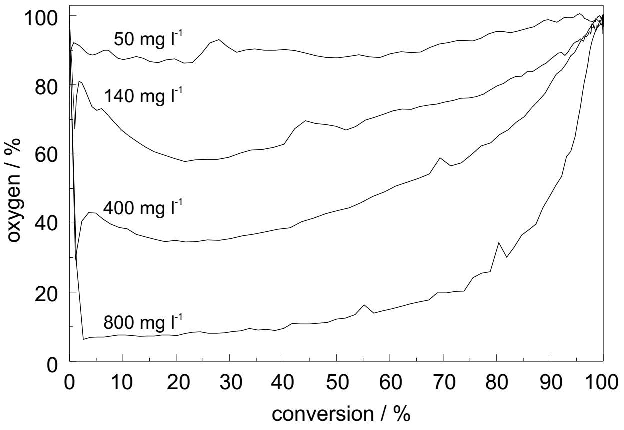

Figure 4:

Plot of the normalized oxygen concentration versus glucose conversion at four different applied catalyst concentrations. Other reaction conditions: $c_{0,\ glucose}$ = 100 mmol l^{-1}, 40 °C, pH 9.

3.2 *Influence of the pH value*

The influence of the pH value on glucose oxidation was studied in the range between pH 7 and pH 10. At the lower pH values of 8 and 7, a higher catalyst concentration of 280 mg l^{-1} or 420 mg l^{-1}, respectively, was used in order to compensate for the expected lower activity. Otherwise, standard reaction conditions were used. For all different runs the concentration of dissolved oxygen was monitored and assured to be higher than 50 %.

The results depicted in Figure 5 show the expected rising activity with increasing pH value. This finding is consistent with results reported for glucose oxidation on various other gold catalysts (Biella et al., 2002; Comotti et al., 2006b; Mirescu et al., 2007; Önal et al., 2004). The selectivity to gluconate always exceeded 99.5 % within the pH range studied here. At pH values higher than 10, the selectivity decreases mainly due to the formation of the alkali-promoted isomerisation products fructose and mannose as already reported in (Biella et al., 2002; Mirescu et al., 2007; Önal et al., 2004). Thus, pH values higher than 10 were not considered in this study. Likewise, glucose oxidation at pH values lower than 7 were not examined due to the expected very low activity. Low activities under neutral or slightly acidic pH values have also been described for the glucose oxidation with other noble metal catalysts based on palladium or platinum, which mainly has been ascribed to a catalyst poisoning by adsorbed free gluconic acid (Besson and Gallezot, 2001a; Mallat and Baiker, 1994).

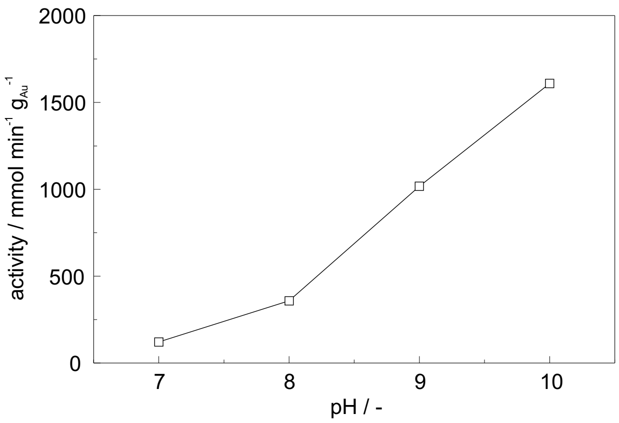

Figure 5:

Influence of the pH value on the catalyst activity. Other reaction conditions: $c_{catalyst}$ = 420 mg l^{-1} at pH 7, $c_{catalyst}$ = 280 mg l^{-1} at pH 8, $c_{catalyst}$ = 140 mg l^{-1} at pH 9 and 10, $c_{0,\ glucose}$ = 100 mmol l^{-1}, 40 °C.

3.3 *Influence of the temperature*

The influence of the temperature on the glucose oxidation was checked within a range between 20 °C and 60 °C. The concentration of dissolved oxygen was monitored only up to a temperature of 40 °C as the applied oxygen electrode has an upper application temperature of 45 °C. During the runs at 20 °C, 30 °C and 40 °C, the normalized oxygen concentration always exceeded 60 % so that external mass transfer limitations were excluded.

The catalyst activity in dependence of the reaction temperature is reported in Table 2. As expected, the activity values strongly increase with increasing reaction temperature, a finding which is consistent with those of Comotti et al. (2006b), Beltrame et al. (2006) and Mirescu et al. (2007) for the same reaction but other types of gold catalysts. In the temperature range studied here, the selectivity was not affected by the temperature and always exceeded 99 %. In order to achieve a high selectivity, temperatures higher than 60 °C are generally not advisable for carbohydrate oxidation as homogeneous reactions such as isomerisation and various degradation reactions leading to brown products are favoured at such high temperatures as already reported for the oxidation of glucose (Mirescu et al., 2007; Önal et al., 2004) as well as for maltose and lactose (Mirescu and Prüße, 2007).

Table 2:

Temperature dependency of the catalyst activity for glucose oxidation. Other reaction conditions: pH 9, $c_{0,\ glucose}$ = 100 mmol l^{-1}, $c_{catalyst}$ = 140 mg l^{-1}.

Temperature °C	Activity mmol min^{-1} g_{Au}^{-1}
20	194
30	285
40	1173
50	1517
60	2165

Within the temperature range between 30 °C and 60 °C, Beltrame et al. (2006) determined an apparent activation energy of 47 kJ mol^{-1} for glucose oxidation on their glucose-stabilized gold colloid. For the present study the Arrhenius plot based on the activities shown in Table 2 is displayed in Figure 6. It shows an apparent activation energy of 53 kJ mol^{-1} for the 0.3 % Au/Al_2O_3 catalyst used here which is in good consistence with Beltrame et al. (2006).

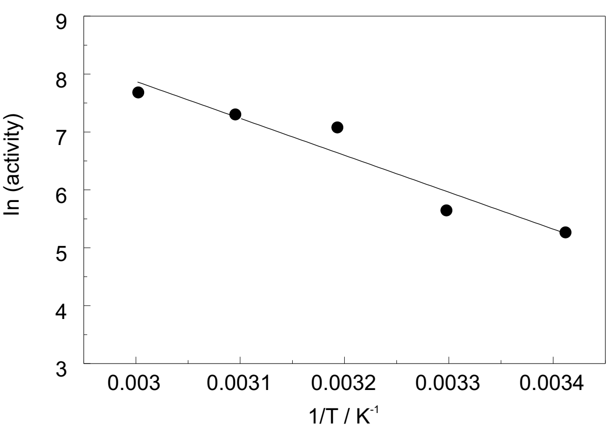

Figure 6:

Arrhenius plot for the determination of the activation energy

3.4 Influence of the initial glucose concentration

The dependence of the reaction rate on the initial glucose concentration has, thus far, only been studied in small concentration ranges, i.e. 100 to 450 mmol l^{-1} by Önal et al. (2004) and 50 to 500 mmol l^{-1} by Beltrame et al. (2006). Further on, the fits of the rate vs. concentration curves in both studies appear quite risky, as are the stated contrary reaction models, i.e., the Langmuir-Hinshelwood model by Önal et al. (2004) or the Eley-Rideal model by Beltrame et al. (2006), deduced from these curves, a point which has already been criticized by Bond et al. (2006).

Hence, a more significant span of initial glucose concentrations, ranging from 10 to 1000 mmol l^{-1} was examined in the present study under otherwise standard reaction conditions. The concentration of dissolved oxygen was tracked for all initial glucose concentrations studied here. The gluconate vs. time together with the normalized oxygen concentration vs. time curves are depicted in Figure 7 for four different initial glucose concentrations. The normalized oxygen vs. time curves suggest no oxygen limitations up to 500 mmol l^{-1} initial glucose concentration, whereas a small oxygen limitation may have occurred at 1000 mmol l^{-1}, as in the latter case the normalized oxygen concentration slightly falls below 50 %.

The catalyst activity in dependence of the initial glucose concentration is displayed in Figure 8 which shows an increasing activity with rising initial glucose concentration up to 500 mmol l^{-1}. At an initial concentration of 1000 mmol l^{-1} the activity is more or less equal to that at 500 mmol l^{-1}. The independence of the rate on the initial glucose concentration as reported by Önal et al. (2004) is not supported by the present results.

Analysis of the reaction order for glucose was carried out both by the differential and integral methods. Similar results were obtained with the two methods showing that the reaction order for glucose is equal to 0.5 as mean value over the whole concentration range studied. However, the integral analysis revealed a decreasing reaction order with increasing initial glucose concentration as it would be expected for a component which adsorbs at the catalyst surface.

3.5 Kinetic model and mechanistic aspects

The discrimination of the kinetic model should not rely solely on the basis of the rate dependence in the initial glucose concentration but should also take into account other reactants. For the present study, the normalized oxygen concentrations shown for different catalyst concentrations in Figure 4 are used to estimate the influence of the dissolved oxygen concentration on glucose oxidation at otherwise equal conditions.

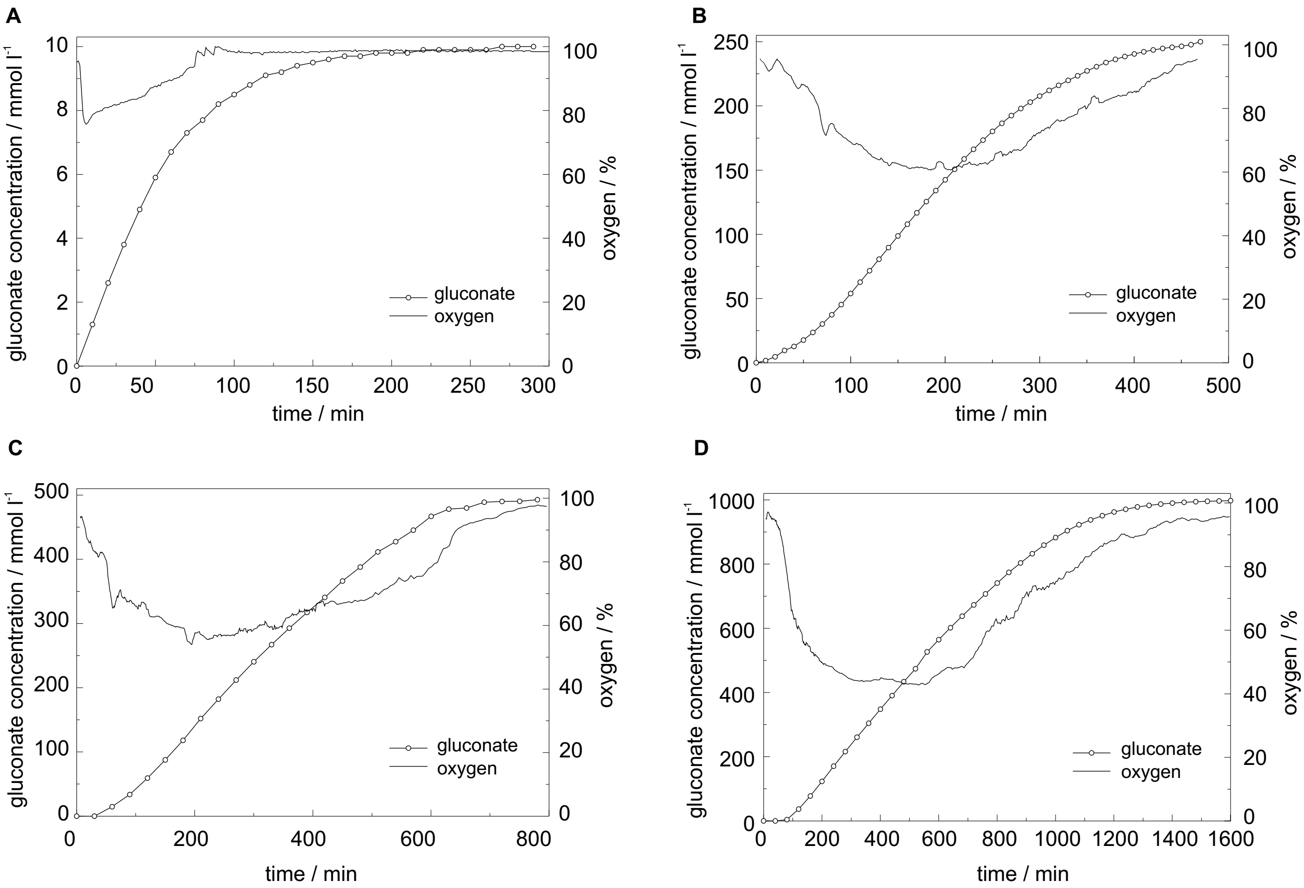

Figure 7:

Gluconate and normalized oxygen concentration versus time plots for an initial glucose concentration of A: 10 mmol l^{-1}, B: 250 mmol l^{-1}, C: 500 mmol l^{-1} and D: 1000 mmol l^{-1}. Other reaction conditions: $c_{catalyst}$ = 140 mg l^{-1}, 40 °C, pH 9.

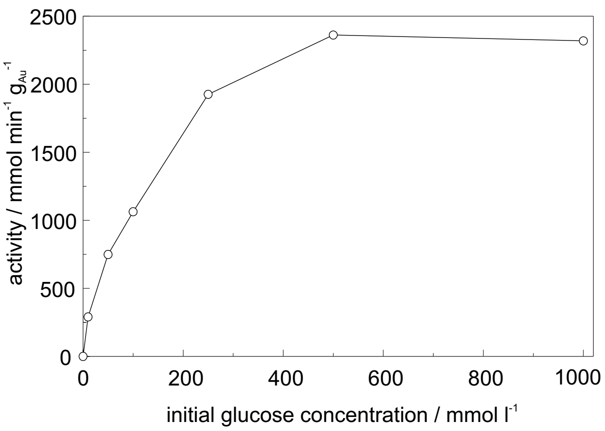

Figure 8:

Influence of the initial glucose concentration on the catalyst activity. Other reaction conditions: $c_{catalyst}$ = 140 mg l^{-1}, 40 °C, pH 9.

Therefore, the catalyst activity in dependence of the medium normalized oxygen concentration between 10 and 50 % glucose conversion, i.e., at the highest reaction rate, was analyzed by the differential method ($log_{activity}$ vs. log_{oxygen} plot). The slope of the fit line, which corresponds to the reaction order of oxygen, lies at a value of about 0.35 suggesting that oxygen adsorption and reaction from the adsorbed state is likely. This value is definitely different from 1, which is the oxygen reaction order proposed by Beltrame et al. (2006) on the basis of two different oxygen partial pressures. The oxygen reaction order of 1 has been used as further evidence for the Eley-Rideal model in that study, which the authors themselves describe as very uncommon for gold-catalyzed reactions.

The reaction order for glucose between 0 and 1 found in this study suggests glucose adsorption on the catalyst as well. Glucose reacting from the adsorbed state has likewise been proposed in the other kinetic studies (Beltrame et al., 2006; Önal et al., 2004). Consequently, as experimental evidence exists that both glucose and oxygen react at the catalyst surface, the Eley-Rideal model for the gold-catalyzed oxidation of glucose proposed by Beltrame et al. (2006) has to be discarded. Consequently, the gold catalyzed glucose oxidation is more likely to follow the Langmuir-Hinshelwood model.

An Eley-Rideal kinetic model also would not fit to the two reaction mechanisms for the gold-catalyzed glucose oxidation currently under discussion. On the one hand, this is the classic oxidative dehydrogenation mechanism which has already been proven for alcohol and carbohydrate oxidation on other noble metal catalysts, e.g., Pt and Pd, (see Gallezot and Besson, 1995; Besson and Gallezot, 2001b, and references therein). According to this mechanism, glucose is first hydrated to the geminal diol that dissociatively adsorbs at the catalyst surface, leading to adsorbed gluconic acid, which desorbs, and an adsorbed hydrogen atom. Adsorbed hydrogen atoms subsequently react with dissociatively adsorbed oxygen to adsorbed water which afterwards desorbs. If no oxygen is present the reaction nonetheless proceeds to a considerable extent.

On the other hand, Comotti et al. (2006c) have suggested a mechanism in which glucose is first attacked by hydroxide leading to the deprotonated geminal diol of glucose. This anionic hydrated glucose species adsorbs at the catalyst surface leading to an electron rich gold which facilitates oxygen adsorption by a nucleophilic attack. Elimination of a proton from the adsorbed glucose species, together with the transfer of another electron from this species to the co-adsorbed anionic oxygen species via gold, results in the gluconate anion and a peroxide-like oxygen species.

Both mechanisms have their strong points and weak points. The classic oxidative dehydrogenation mechanism is able to explain the formation of hydrogenated products, which have been described by Önal et al. (2004) for the gold-catalyzed glucose oxidation, as the catalyst surface is covered by reactive hydrogen species during the oxidation reaction. However, the observed activity rises with increasing pH value and the observed formation of hydrogen peroxide (Beltrame et al., 2006; Comotti et al., 2006c) can not be understood on the basis of this mechanism. In contrast, both the promoting effect of alkali and H_2O_2 formation can easily be understood by the Comotti mechanism. However, according to their mechanism, hydrogenated products can not be formed as the catalyst's surface is not covered with reducing hydrogen species at any time. It is further stated that glucose conversion to gluconic acid does not proceed under oxygen-free conditions; hence, oxygen is an essential compound in the reaction mechanism (Beltrame et al., 2006).

To clarify the situation for the gold catalyst used in the present study, analysis for both hydrogen peroxide and glucose conversion under oxygen-free conditions was carried out. As it can be taken from Figure 9 large amounts of hydrogen peroxide could be detected during the course of this reaction. Thus, the findings of Comotti et al. (2006c) are confirmed in this regard.

Glucose conversion to gluconic acid under oxygen-free conditions was carried out with a larger amount of catalyst (10000 mg l^{-1}) according to the procedure described in Section 2.7. If the reaction was carried out under otherwise standard reaction conditions, namely pH 9, only a very low glucose conversion (< 1 %) could be detected within 24 h. However, by adjusting a slightly higher pH value of 10.5, a considerable reaction rate could be achieved. During another 60 h, about 80 % glucose conversion was obtained. Analysis of the reaction mixture after this additional 60 h revealed that not only gluconic acid was produced to about 44 % of the total amount of formed products, but also hydrogenated products, mainly sorbitol, mannitol and xylitol, to about 28 % in the sum. The other products were the alkaline isomerisation products fructose and mannose (together 28 %), formed in a homogeneous reaction. No hydrogen peroxide formation could be detected during this experiment.

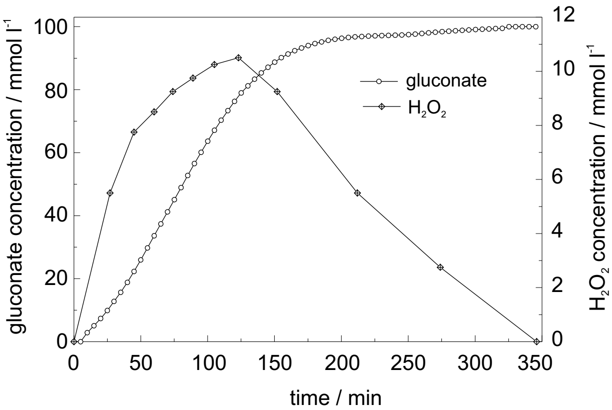

Figure 9:

Gluconate and hydrogen peroxide concentration versus time plot for a catalyst concentration of $c_{catalyst}$ = 200 mg l^{-1} at otherwise standard reaction conditions.

According to these findings, a mechanism for the gold catalysed glucose oxidation is most probable which is in between the classic oxidative dehydrogenation mechanism and the one suggested by Comotti et al. It seems reasonable to assume that the reaction starts with a nucleophilic attack of a hydroxide ion on glucose leading to a deprotonated geminal diol of glucose, which in the second step is likely to adsorb at the catalyst surface leading to electron-rich gold as shown in Figure 10. Thus far, the steps have already been suggested by Comotti et al. (2006c), who already pointed out that this pathway can easily explain reaction enhancement by alkali. Depending on whether or not oxygen is present in a sufficient amount, this adsorbed glucose species may react in two different ways.

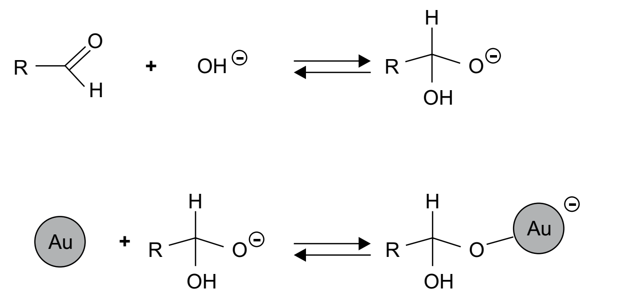

Figure 10:

Formation of the deprotonated geminal diol of glucose by nucleophilic attack of a hydroxide ion on glucose and adsorption of the formed glucose species at the gold surface

If no oxygen is present, the adsorbed glucose species is likely to decompose by hydrogen transfer to the catalyst surface as shown in Figure 11. This results in a desorbed gluconic acid species, which is further deprotonated to the gluconate anion under the alkaline reaction conditions, and hydrogen adsorbed at the catalyst surface, which is the source for the hydrogenated products observed under oxygen-free conditions in the present study.

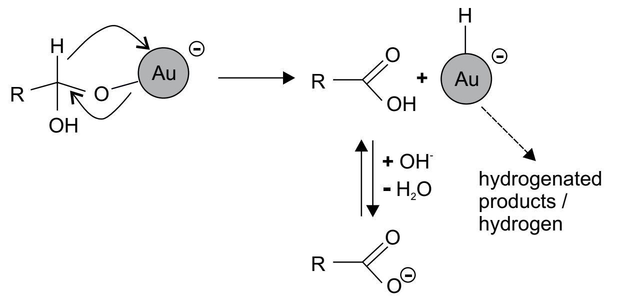

Figure 11:

Further reaction pathway of the adsorbed glucose species under oxygen-free conditions

If oxygen is present it will also adsorb at the catalyst surface according to the scheme shown in Figure 12. The linear oxygen adsorption, as well as oxygen and the glucose species being adsorbed simultaneously, have already been suggested by Comotti et al. (2006c). Their suggestion of an activated oxygen adsorption by the electron-rich gold surface likewise seems reasonable as adsorbed O_2^- species are favoured (Bond et al., 2006). However, from this state on, in our opinion, it seems to be more likely that the adsorbed glucose species will decompose in the same way as under oxygen-free conditions by hydrogen transfer to the gold surface. After gluconic acid desorption both a hydrogen species and the linear O_2^- species are co-adsorbed at the catalyst surface. Those two species will react in the final step to an adsorbed peroxide species which subsequently desorbs.

By this mechanism the formation of hydrogen peroxide and the formation of hydrogenated products can be explained. Oxygen is needed to clean the catalyst surface from adsorbed hydrogen. If oxygen is not present, or if oxygen adsorption is slow compared to glucose adsorption, hydrogenated products are produced.

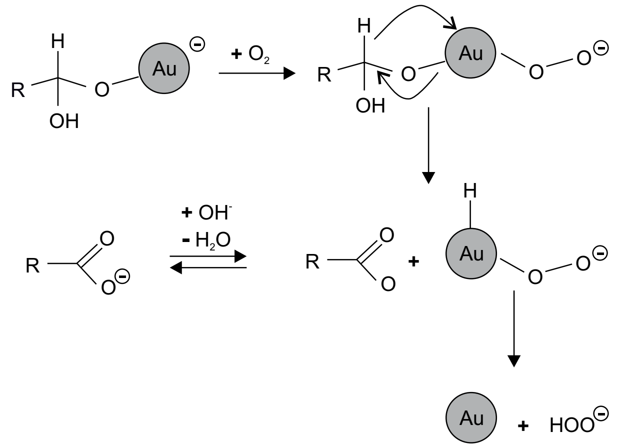

Figure 12:

Further reaction pathway of the adsorbed glucose species if oxygen is present

The main difference of the mechanism proposed here, and the classic oxidative dehydrogenation mechanism, is the fact that the gold catalyst adsorbs oxygen not dissociatively but in a linear manner. Linearly adsorbed oxygen results in peroxide species whereas dissociatively adsorbed oxygen would lead to water as product as it is formulated in the classic oxidative dehydrogenation mechanism proven for palladium and platinum based catalysts. This difference in oxygen chemisorption of the gold catalyst compared to palladium and platinum catalysts might also be the reason for the unusual high selectivity of gold in carbohydrate oxidation compared to palladium and platinum.

4. Conclusions

The kinetics of the liquid-phase glucose oxidation to gluconic acid has been investigated using a 0.3 % Au/Al_2O_3 catalyst prepared by the incipient wetness method. Oxygen mass transfer limitations were found to influence the catalytic activity below 50 % dissolved oxygen with regard to its saturation level. An increasing activity was found with increasing pH value in the range between pH 7 and 10 and with increasing temperature in the range between 20 and 60 °C, whereas the selectivity to gluconic acid remained unchanged at > 99 % under these conditions. The activation energy was determined to be 53 kJ mol^{-1}.

Compared to other kinetic studies of the gold-catalyzed glucose oxidation (Beltrame et al., 2006; Önal et al., 2004), a broader initial glucose concentration range between 10 and 1000 mmol l^{-1} was investigated in the present study. Analysis of the reaction orders with regard to glucose and oxygen led to the conclusion that the Eley-Rideal model should be discarded for the gold-catalyzed glucose oxidation.

During glucose oxidation with oxygen, considerable amounts of hydrogen peroxide are formed. The gold catalyst is able to oxidise glucose to gluconic acid under oxygen-free conditions; considerable amounts of hydrogenated products are also formed under these conditions. Both observations can be explained by a modified oxidative dehydrogenation mechanism, in which hydrogen from the adsorbed sugar is transferred to the catalyst surface where it reacts with a co-adsorbed linear oxygen molecule leading to hydrogen peroxide.

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