Evelyn Müller

Das Dammkultur-System nach Turiel

- Untersuchungen auf der Hessischen Staatsdomäne Frankenhausen -

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Erster Gutachter: Prof. Dr. Holger Wildhagen
Zweiter Gutachter: Prof. Dr. Rainer Georg Jörgensen

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Evelyn Müller, Holger Wildhagen, Michael Quintern, Jürgen Heß, Florian Wichern, Rainer Georg Joergensen

Spatial patterns of soil biological and physical properties in a ridge tilled and a ploughed Luvisol
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Abkürzungsverzeichnis

AB	Ackerbohne
ANOVA	Varianzanalyse (engl. analysis of variance)
a.s.l.	über dem Meeresspiegel (engl. above sea level)
BBCH	Biologische Bundesanstalt für Land- und Forstwirtschaft, Bundessortenamt und Chemische Industrie
BBV	Bodenbearbeitungsversuch
C	Kohlenstoff (engl. carbon)
$CaCl_2$	Calciumchlorid
$CHCl_3$	Chloroform
CIRAS	Combined infrared gas analysis system
C_{mic}	mikrobiell gebundener Kohlenstoff
CO_2	Kohlendioxid
Cr	Dammkrone (engl. crown)
CV	Variationskoeffizient (engl. coefficient of variance)
DFH	Domäne Frankenhausen
Dk	Dammkultur (System)
DLG	Deutsche Landwirtschafts-Gesellschaft
E	Ecomat (System)
E_C	organischer Kohlenstoff, extrahiert aus fumigiertem Boden - organischer Kohlenstoff, extrahiert aus nicht fumigiertem Boden
E_N	Gesamtstickstoff, extrahiert aus fumigiertem Boden - Gesamtstickstoff, extrahiert aus nicht fumigiertem Boden
F	Furche (engl. furrow)
FAO	Food and Agriculture Organization of the United Nations
GC	Gaschromatograph
k_{EC} und k_{EN}	mikrobiell gebundener, extrahierbarer Anteil des Gesamtkohlenstoffs und des Gesamtstickstoffs
kfK	keimfähige Körner
KG	Kleegras

K_2SO_4	Kaliumsulfat
LLH	Landesbetrieb Landwirtschaft Hessen
IRGA	Infrared gas analyzer
N	Stickstoff (engl. nitrogen)
NaOH	Natriumhydroxid
NH_4^+	Ammonium
N_{mic}	mikrobiell gebundener Stickstoff
N_{min}	anorganischer (mineralischer) Stickstoff
NO_3^-	Nitrat
N_2O	Distickstoffmonoxid
P	Pflug (System)
PVC	Polyvinylchlorid
S	Flanke (engl. shoulder)
SW	Sommerweizen
TM	Trockenmasse
Ut3	mitteltoniger Schluff
veg.	Vegetation

1 Einleitung

Die heutige Landwirtschaft ist geprägt durch vielfältige Systeme der Bodenbearbeitung. Grundsätzlich unterscheidet man die konventionelle Bodenbearbeitung (Pflugwirtschaft), die reduzierte oder konservierende Bodenbearbeitung (pfluglose Bewirtschaftung) sowie die Direktsaat (Diepenbrock et al., 2005). Diese Bodenbearbeitungssysteme differieren hinsichtlich Eingriffsintensität und Bearbeitungstiefe. Dies führt zu systembedingten Einflüssen auf bodenphysikalische, bodenbiologische und bodenchemische Eigenschaften (Franzluebbers et al., 1995). Das Hauptziel der Bodenbearbeitung ist es, ein möglichst optimales Saat- und Keimbett für die Pflanzen bereit zu stellen. Die hierfür bearbeitete Bodenoberfläche kann, je nach System und Kulturart, unterschiedliche Formen haben. Ein Bodenbearbeitungssystem mit einem erhöhten Saatbett und damit einer besonderen Oberflächenform ist das Dammkultur-System.

Das Dammkultur-System ist, wie der Pflug, ein altes und weltweit verbreitetes Bodenbearbeitungssystem, welches jedoch weniger häufig Verwendung findet. Dammkultur-Systeme entwickelten sich in Süd- und Mittelamerika (Turner and Harrison, 1981), in Afrika (Pereira et al., 1967) und in Süd-Ost-Asien (Chandler, 1981). Ursprünglich stammt das System aus tropischen Gebieten, welche durch flachgründige, wenig fruchtbare Böden mit wenig Niederschlag geprägt waren (Lal, 1990). Durch das Häufeln bzw. das erhöhte Saatbett wird der durchwurzelbare Raum für die Pflanzen vergrößert (Benjamin et al., 1990) und eine bessere Wasserversorgung gewährleistet. In ariden und semi-ariden Gebieten bietet die Dammkultur die Möglichkeit der Bewässerung der Pflanzen durch Einleiten von Wasser in die Furchen (Gebreegziabher et al., 2008). In humiden Gebieten mit schweren Böden ermöglicht die Dammkultur ein schnelleres Abtrocknen und damit eine frühzeitigere Bearbeitbarkeit der Flächen im Frühjahr (Benjamin et al., 1990; Gupta et al., 1990).

Es gibt verschiedene Typen des Dammkultur-Systems. Gemein haben sie jedoch das Ziel, ein Saatbett oberhalb der eigentlichen, natürlichen Bodenoberfläche zu schaffen (Hatfield et al., 1998). Dammkultur-Systeme lassen sich hinsichtlich der Verweildauer der Dämme auf dem Feld und deren Form unterscheiden.

Die Nutzung von mehrjährigen, im Feld verbleibenden Dämmen („permanent ridges“) ist besonders im amerikanischen Corn Belt verbreitet (Al-Kaisi et al., 2005). Dabei werden, häufig im Herbst, die Dämme geformt und über Jahre in einer Mais- (*Zea mays* L.) und Sojabohnen- (*Glycine max* L.) Rotation genutzt (Pikul Jr. et al., 2001; Archer et al., 2002). Dieses mehrjährige Dammkultur-System ist geprägt durch eine Sequenz bestimmter Bodenbearbeitungsschritte (Hatfield et al., 1998) (Abb. 1): Grundsätzlich gibt es keine bodenbearbeitenden Maßnahmen zwischen Ernte und Aussaat. Zur Aussaat werden die Dammkrone und die Dammflanken von Pflanzenresten gesäubert. Dies geschieht mit Hacken oder Striegeln, wobei abgetragener Boden sowie Pflanzenreste in den Dammfurchen verbleiben und eine Mulchdecke bilden. Das Saatgut wird direkt im Damm abgelegt, häufig in Kombination mit Dünger oder Pflanzenschutzmitteln. Nachdem die Pflanzen eine entsprechende Größe erreicht haben, werden die Dämme gehäufelt. Hierbei wird das Bodenmaterial mit den Pflanzenresten aus der Furche zur Dammkrone hin verlagert.

Durch diese Maßnahmen wird nur etwa 1/3 der Bodenoberfläche des Dammes bearbeitet. Dieses Dammkultur-System zählt zu den reduzierten Bodenbearbeitungssystemen, da die Mulchdecke und die geringe Eingriffsintensität Bodenerosion mindern (Lal, 1990; Hatfield et al., 1998).

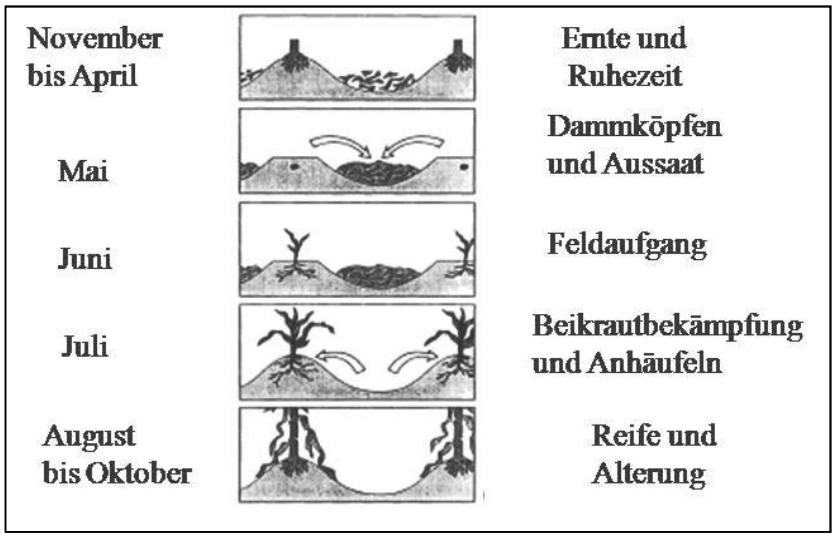

Abbildung 1: Bodenbearbeitungssequenz bei der Nutzung von mehrjährigen Dämmen nach Forcella und Lindstrom (1988).

Eine weitere Form der Dammkultur ist das „raised bed“ System, welches mehr- oder einjährig u.a. in Mexico genutzt wird (Rawson und Mcpherson, 2000; Govaerts et al., 2007) (Abb. 2). Bei diesem System handelt es sich um leicht erhöhte feldlange Anbauflächen, auf denen in Reihen ausgesät wird. Die Anzahl der Reihen wird durch die Fruchtart bestimmt. Einzelkornsaaten wie Sojabohne und Mais werden in einer Reihe, Weizen (*Triticum aestivum* L.) in zwei bis drei Reihen ausgesät (Govaerts et al., 2006). Die Furchen zwischen den Beeten dienen in diesem System vorwiegend der Bewässerung. Bei einer mehrjährigen Nutzung werden nur die bereits bestehenden Drillreihen bearbeitet und direkt in die entstandene Mulchschicht gesät (Rawson und Mcpherson, 2000).

In Afrika ist ein weiteres Dammkultur-System mit so genannten „tied ridges“ verbreitet (Abb. 3). Hierbei werden zwischen zwei Dämmen niedrigere Querdämme eingezogen. Diese verhindern einen oberflächigen Abfluss des Regenwassers. Das angestaute Wasser kann in den Boden über einen längeren Zeitraum infiltrieren (Netting, 1968). Dieses System spielt besonders in regenärmeren, durch Starkregen beeinflussten Gebieten eine Rolle. In Ermangelung an entsprechender Technik erfolgt das Formen dieser Dämme häufig mit einer Hacke oder einem einfachen Pflug, selten mit einem Traktor als Zugmittel. Die Dämme werden sowohl einjährig als auch mehrjährig genutzt (Shaxon und Barber, 2003).

Abbildung 2: „Raised beds“ mit einer Breite von 60-80 cm in Mexico (Rawson und Mcpherson, 2000).

Abbildung 3: „Tied ridges“ in einem Dammkultur-System in Afrika (Shaxon und Barber, 2003).

Im europäischen Raum wird das Dammkultur-System überwiegend für den Anbau von Kartoffeln (*Solanum tuberosum* L.) (Abb. 4) genutzt, um die Ernte zu erleichtern. Weitere Kulturen, die in Dammkultur angebaut werden, sind Möhren (*Daucus carota* L.) und Spargel (*Asparagus officinalis* L.). Die hierbei genutzten Dämme unterscheiden sich von den Kartoffeldämmen hinsichtlich ihrer Form und damit ihrer Entstehung (Abb. 5). Grundsätzlich werden für das Formen der Dämme Walzen, Bleche oder Schare genutzt. Die eingesetzten Geräte bestimmen die Dammform. Durch Walzen und Bleche entstehen trapezförmige Dämme, wie sie im Möhren- und Spargelanbau verwendet werden. Hierbei fährt häufig eine Fräse voraus, um ein möglichst feinkrümeliges Saatbett zu erhalten. Werden die Dämme mit Scharen geformt, hat der Damm eine gewölbte Oberfläche, vergleichbar mit den Dämmen im Kartoffelanbau.
Die destruktive Art der Ernte dieser Kulturen lässt nur eine einjährige Nutzung der Dämme zu.

Abbildung 4: Kartoffeldämme auf der Hessischen Staatsdomäne Frankenhausen.

Abbildung 5: Möhrendämme auf der Hessischen Staatsdomäne Frankenhausen.

Begründet durch die besondere Form der Erdoberfläche haben Dammkultur-Systeme bedeutende Vorteile gegenüber dem Flachanbau. Positive Eigenschaften, die dem permanenten Dammkultur-System zugesprochen werden sind eine schnellere Erwärmung und Abtrocknung des Bodens im Frühjahr (Cox et al., 1990;

Pikul Jr. et al., 2001). Hierdurch kann zeitiger gesät bzw. auf schweren Böden der Saattermin eingehalten werden. Die höhere Temperatur führt zu einer schnelleren Keimung der Samen (Buchele et al., 1955). Durch die Mulchschicht wird der Boden gegen Wasser- und Winderosion geschützt (Behn, 1985; Norton and Brown, 1992), gleichzeitig verbessert sie die Wasserspeicherung in den Furchen. Pflanzen, die auf Dämmen wachsen, sollen auf Grund der geringeren Lagerungsdichte besser mit Wasser (Liebig et al., 1993; Bargar et al., 1999) und auf Grund der höheren mikrobiellen Aktivität besser mit Nährstoffen versorgt werden. Dies kann zu höheren Gehalten an Inhaltsstoffen und Erträgen (Cox et al., 1990) führen. Dammkultur-Systeme tragen zu einem verminderten Herbizideinsatz (Lal, 1990), einem verminderten Kraftstoffverbrauch und einem geringeren Arbeitskräfteeinsatz bei (Behn 1985; Liebig et al., 1995). Diese potentiellen Vorteile des Dammkultur-Systems werden jedoch wissenschaftlich ebenso kritisch betrachtet und durch weitere Studien eingeschränkt oder widerlegt. Waddell und Weil (1996) sehen eine Gefahr im schnelleren Abtrocknen der Dämme, da dies mit einem aufwärts gerichteten Wasserstrom und damit mit Stoffverlagerung und einem Verlust an Bodenwasser einhergeht. Borin und Sartori (1995) berichten von niedrigeren Mais- und Sojabohnenerträgen in der Dammkultur im Vergleich zu konventionell bearbeiteten Flächen. Zu ähnlichen Ergebnissen kamen ebenfalls Pikul Jr. et al., (2001). Auch Nokes et al. (1997) konnten während eines 5-jährigen Feldversuches (1991-1995) keine Ertragsunterschiede für Mais und Sojabohnen zwischen der Dammkultur, der Direktsaat und einer gegrubberten Variante nachweisen. Archer et al. (2002) fanden keinen signifikanten Unterschied in den eingesetzten Düngermengen zwischen Dammkultur-System und dem konventionellen Pflug-System. Darüber hinaus stellten sie einen signifikant höheren Bedarf an Pestiziden im Dammkultur-System fest.

Auf Grund der Menge an wissenschaftlichen Untersuchungen kann das konventionell bearbeitete (unter Einsatz von Herbiziden und Düngemitteln), mehrjährige Dammkultur-System kontrovers diskutiert werden. Das Dammkultur-System im ökologischen Landbau hingegen war bis auf die Untersuchung von Metzke et al. (2007), welche sich mit dem Regenwurmbesatz beschäftigt bisher nicht Gegenstand wissenschaftlicher Untersuchungen. Es fehlen grundlegende

wissenschaftlich fundierte Daten, welche beispielsweise den Einfluss des Häufelns auf die mikrobiellen Aktivität, die mikrobieller Biomasse und die Lagerungsdichte untersuchen. Außerdem ist wenig über die Erträge und nichts über den Gehalt an Inhaltsstoffen im Erntegut bekannt. Durch diese Wissenslücken fehlt jegliche Basis für eine Diskussion und eine objektive Bewertung des Dammkultur-Systems.

Die vorliegende Arbeit soll beginnen, diese Wissenslücken zu schließen. Hierbei soll das Dammkultur-System nach Turiel bezüglich folgender Punkte mit dem Pflug-System verglichen werden: (1) der Untersuchung kleinräumigen bodenbiologischen und bodenphysikalischen Unterschiede innerhalb und zwischen den Bodenbearbeitungssystemen; (2) der Messung der CO_2 Freisetzung zur Bestimmung der mikrobiellen Aktivität. Zudem wurden drei *in situ* CO_2 Messmethoden hinsichtlich ihrer Messgenauigkeit im Feld verglichen; (3) der Möglichkeit der Übertragung einiger Eigenschaften des mehrjährigen Dammkultursystems auf das hier untersuchte einjährige ökologisch bewirtschaftete Dammkultur-System nach Turiel. Abschließend soll die quantitative und qualitative Bewertung der Erträge zu weiteren Erkenntnissen beitragen.

Die damit verbundenen Untersuchungen fanden auf dem Bodenbearbeitungsversuch auf der Hessischen Staatsdomäne Frankenhausen statt.

2 Der Bodenbearbeitungsversuch auf der Hessischen Staatsdomäne Frankenhausen

2.1 Die Hessische Staatsdomäne Frankenhausen

Die Hessische Staatsdomäne Frankenhausen wird seit Juli 1998 von der Universität Kassel als Lehr-, Versuchs- und Transferzentrum für Ökologische Landwirtschaft und nachhaltige Regionalentwicklung gepachtet. Die Domäne liegt circa 15 km nördlich von Kassel in der Hofgeismarer Rötsenke. Das 30-jährige Mittel für Niederschlag beträgt 699 mm und die Jahresdurchschnittstemperatur liegt bei 8,5°C für diese Region. Seit Pachtbeginn 1998 wird die Domäne nach den Richtlinien des Ökologischen Landbaus bewirtschaftet und ist Mitglied im Bioland- und Naturlandverband. Der Wirtschaftsbetrieb umfasst eine Fläche von circa 320 ha, wovon 229 ha als Ackerland und 36 ha als Grünland bewirtschaftet werden. Die restlichen Flächen werden unterverpachtet oder stehen dem Versuchswesen zur Verfügung. Darüber hinaus wurde seit Pachtbeginn eine Milchviehherde aufgebaut und Freilandgänse sowie Freilandschweine gehalten.

2.2 Lage und Bodenkenndaten des Bodenbearbeitungsversuchs

Der Bodenbearbeitungsversuch (BBV) wurde als Dauerversuch im Rahmen des Verbundprojektes „Reduzierte Bodenbearbeitungssysteme im Ökologischen Landbau“ 2002 angelegt und befand sich 2003 im ersten Versuchsjahr. Auf dem Versuch werden folgende drei Bodenbearbeitungssysteme gegenübergestellt: das herkömmliche Pflug-System, das Dammkultur-System nach Julian Turiel und das Ecomat-System der Firma Kverneland. Der Versuch dient zum Einen der Beseitigung von Wissenslücken, die für die beiden letztgenannten Systeme in der Praxis bestehen. Zum Anderen soll der BBV die Möglichkeit bieten, die Systeme besonders für ihren Einsatz im Ökologischen Landbau anzupassen und zu bewerten. Der Bodenbearbeitungsversuch liegt auf dem Schlag Lindenbreite im Westen der Domäne Frankenhausen (Abb. 6).

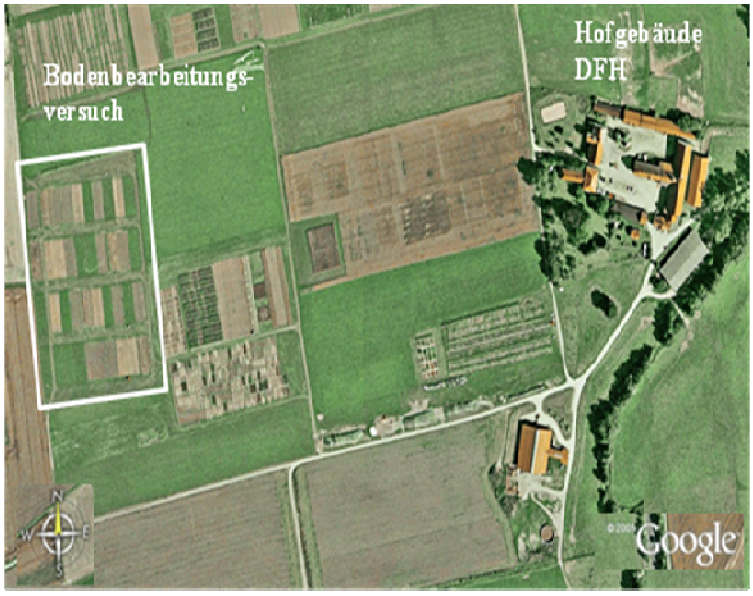

Abbildung 6: Der Bodenbearbeitungsversuch auf den Flächen der Hessischen Staatsdomäne Frankenhausen (Google Earth, 2005).

Dieser Bereich der Domäne ist mit einer bis zu 7,5 m hohen Lößschicht bedeckt. Die Hangneigung beträgt circa 5% in süd-östliche Richtung. Der Boden ist nach den FAO Richtlinien als Haplic Luvisol bzw. nach der bodenkundlichen Kartieranleitung Nr. 4 (AG Boden, 1996) als Parabraunerde aus Löß klassifiziert worden. Der Boden besteht aus 2,0% Sand, 81,2% Schluff und 16,8% Ton (Ut3) (Brandt und Heß, 2004). Der pH-Wert liegt bei 6,8 ($CaCl_2$). Der Gehalt des organischen Kohlenstoffs liegt bei 1,1 und der des organischen Stickstoffs bei 0,1%.

2.3 Die Versuchsanlage

Der Versuch ist eine vollständig randomisierte Blockanlage mit den zwei Prüffaktoren Kultur und Bodenbearbeitungssystem (Abb. 7). Die Anlage besteht aus 4 Blöcken mit jeweils neun Parzellen. Die Parzellen sind 12 (Pflug und Ecomat) bzw. 15,3 m (Dammkultur) breit und 35 m lang. Die Breite der Dammkulturparzellen ergibt sich aus der Dammbreite von jeweils 90 cm. Begrenzt durch die Arbeitsbreite des Turielgerätes werden gleichzeitig vier Dämme geformt. Auf der Parzelle befinden sich insgesamt 16 vollständige Dämme und jeweils zu Beginn und am Ende der Parzelle ein halber Damm, der durch die Dammformung

entsteht. Die Gesamtfläche des Versuches beträgt 2,85 ha. Die Fruchtfolge des Versuchs ist: zweijähriges Kleegras - Sommerweizen - (Zwischenfrucht) - Kartoffeln - (Zwischenfrucht) – Ackerbohne (*Vicia faba* L.) – Wintergerste (*Hordeum vulga*re L.). Die Saatmenge für die Zwischenfrucht beträgt 24 kg Senf und 8 kg Ölrettich. Das Kleegras in Dammkultur wurde auf ebenen Boden angebaut, um die Ernte zu erleichtern.

Die Aussaat der Fruchtarten erfolgte zunächst als Breitsaat und wurde 2007 zur Aussaat von Wintergerste auf Drillsaat (Reihenabstand 8-10 cm) umgestellt. Der Versuch wird nach dem „Ceteris paribus“ Prinzip bewirtschaftet. Dies bedeutet, nicht alle Parzellen werden zwingend am gleichen Tag bearbeitet sondern zu einem systemgeeigneten Zeitpunkt, wobei alle anderen Bedingungen (Bsp. Sorten, Aussaatstärken) gleich bleiben. Dies wurde nötig, da die Parzellen der einzelnen Bodenbearbeitungssysteme unterschiedlich abtrockneten und damit befahrbar waren. Eine zeitgleiche Bodenbearbeitung war somit nicht möglich und hätte auch nicht der guten landwirtschaftlichen Praxis entsprochen. Tabelle 1 zeigt die Bodenbearbeitungsmaßnahmen, die 2007 für Ackerbohne und Sommerweizen auf dem Versuch durchgeführt wurden.

Der Biomasseverlust an Kleegras, welches geschnitten und abgefahren wird, wurde bis 2007 durch die entsprechende Menge (1,47 Großvieheinheiten) Bioabfallkompost ersetzt, später entfiel die organische Zufuhr.

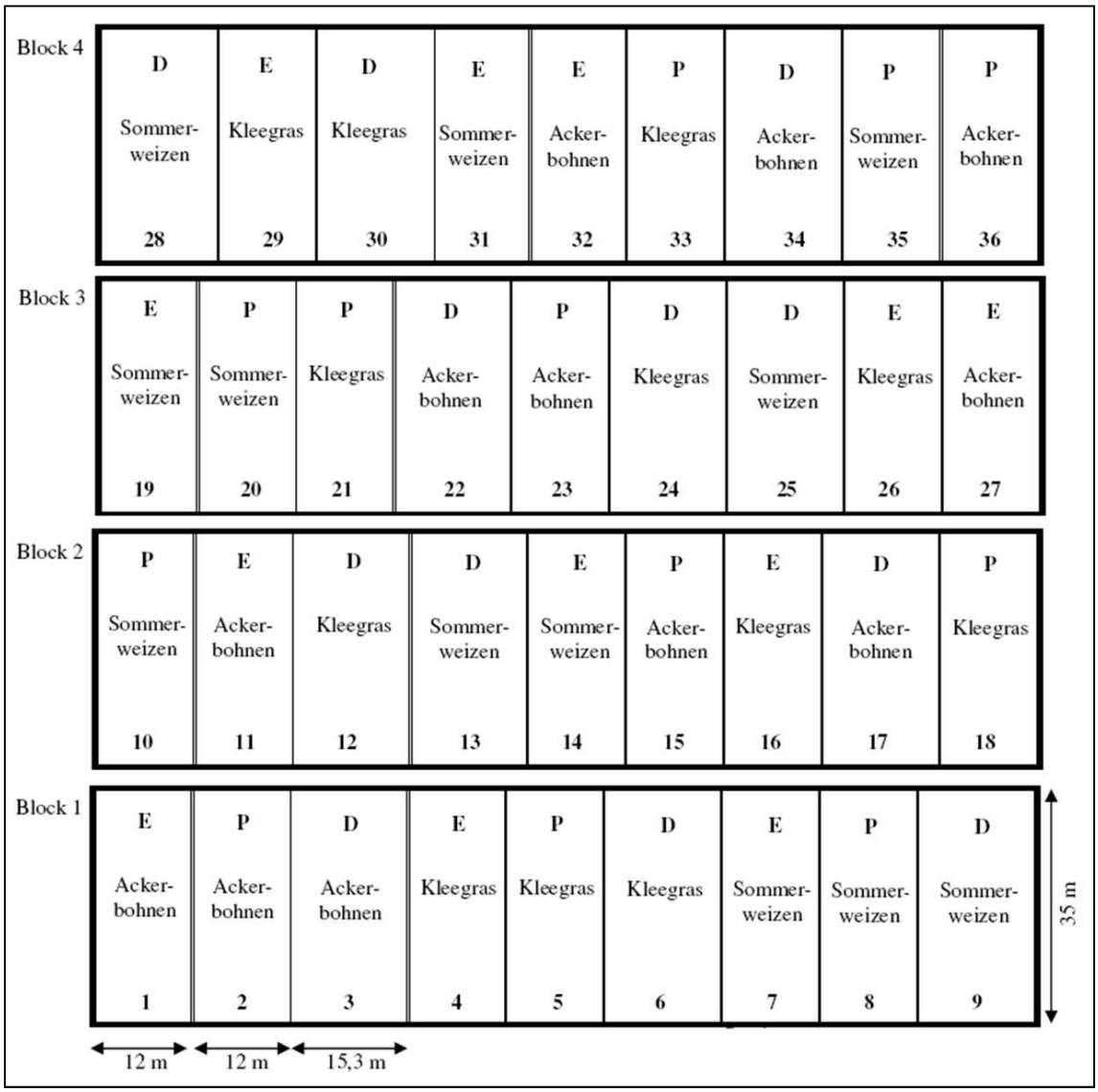

Abbildung 7: Versuchsplan mit Parzellennummern, Kulturarten und Bodenbearbeitungssystemen für den Bodenbearbeitungsversuch auf der Hessischen Staatsdomäne Frankenhausen 2007. (P = Pflug, D = Dammkultur, E = Ecomat).

Tabelle 1 Bodenbearbeitungsmaßnahmen auf dem Bodenbearbeitungsversuch für Sommerweizen (SW) und Ackerbohne (AB) 2007. (KG = Kleegras, kfK = keimfähige Körner).

	Datum	**Maßnahme**
Pflug	28.03.	Pflügen in AB und SW (25 cm tief)
	04.04.	Kreiselegge
	04.04.	Aussaat AB (50 kfK/m²; Sorte: Divine)
	04.04.	Aussaat SW (500 kfK/m²; Sorte: Triso)
	15.08.	Drusch SW
	16.09.	Drusch AB
Dammkultur	03.04.	KG gegrubbert
	11.04.	Kreiselegge in KG-Dammkultur (für SW)
	11.04.	Häufeln von KG-Dammkultur (30 cm tief)
	11.04.	Umhäufeln von Zwischenfrucht für AB
	14.04.	Aussaat AB-Dammkultur
	14.04.	Aussaat SW-Dammkultur
	15.08.	Drusch SW
	17.09.	Drusch AB
Ecomat	28.03.	Ecomat in AB und SW (12 cm tief)
	04.04.	Kreiselegge
	04.04.	Aussaat AB (50 kfK/m²; Sorte: Divine)
	04.04.	Aussaat SW (500 kfK/m²; Sorte: Triso)
	15.08.	Drusch SW
	16.09.	Drusch AB

2.4 Die Bodenbearbeitungssysteme

Das Pflug-System ist gekennzeichnet durch eine Bearbeitungstiefe von 25 cm. Die anschließende Vorbereitung des Saatbettes erfolgte mit einer Kreiselegge (6-8 cm tief). Die Aussaat wurde mit einer Drillmaschine der Firma Nordstern durchgeführt. Der Pflug ist ein 3-Schar Volldrehpflug mit einer Arbeitsbreite von 1,05 m. Pflegemaßnahmen wurden mit Hacken oder Striegel durchgeführt, Stoppeln wurden durch zweimaliges Grubbern bearbeitet. Die Zwischenfrüchte wurden direkt nach der Stoppelbearbeitung eingesät und mit dem Pflug umgebrochen (Brandt und Heß, 2004).

Das Dammkultur-System Turiel hat seinen Namen von Julian Turiel, der das Gerät zur Formung von Dämmen entwickelt und gebaut hat. Das System trägt auch den

Namen Häufelpflug, der historisch gesehen jedoch für einen Pflug mit einem einfachen Streichblech verwendet wurde. Hier entstand jeweils nur ein halber Damm bei einer „Befahrung“. Das Turiel-System besteht aus einem Eisenrahmen, an den flexibel Bearbeitungsgeräte angebaut werden können (Abb. 8). Die wichtigsten Bestandteile sind die Häufelkörper mit denen die Dämme geformt werden, der Boden jedoch nicht gewendet wird. Zur Pflege des Bestandes können entsprechende Geräte (Striegel, Fingerhacken) in verschiedenen Abständen an den Rahmen angebaut werden. Für das Aufbrechen von Bodenverdichtungen im Unterboden steht ein Tiefenlockerer zur Verfügung (Abb. 10). Das auf der Domäne Frankenhausen verwendete Gerät formt gleichzeitig vier Dämme mit einer Breite von jeweils 90 cm und einer Höhe von circa 20 cm. Durch das Aufsatteln einer pneumatischen Sämaschine sind ein gleichzeitiges Formen und die Saatgutablage in den Damm möglich. Kurz vor dem Auflaufen wurden die Dämme mit einer Stahlkette abgeschleppt, damit die Keimlinge leichter die Bodenoberfläche durchdringen können (Brandt und Heß, 2004).

Das Ecomat-System der Firma Kverneland ist ein flach wendendes Bodenbearbeitungssystem mit einer Arbeitstiefe von 10-18 cm. Das Ecomat-System besteht aus einem Pflug für die Grundbodenbearbeitung und aus einem integrierten Packer, der das Saatbett vorbereitet. Ausgesät wurde mit einer Drillmaschine der Firma Nordstern. Die Pflegemaßnahmen finden ähnlich denen des Pflug-Systems statt (Brandt und Heß, 2004).

Abbildung 8a: Das Dammkulturgerät mit aufgesattelter pneumatischer Sämaschine (Wildhagen, 2003).

Abbildung 8b: Das Dammkulturgerät mit aufgesattelter pneumatischer Sämaschine (Wildhagen, 2003).

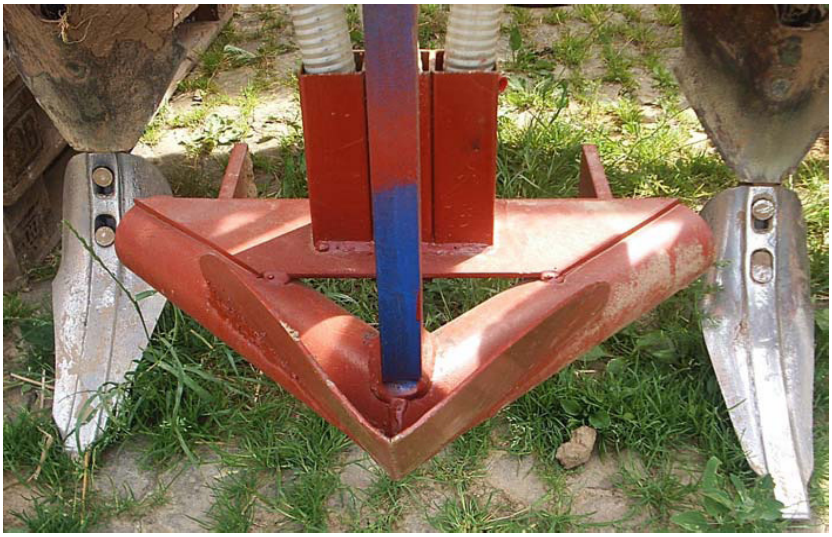

Abbildung 9: Das Säaggregat der pneumatischen Drillmaschine. Im Hintergrund befinden sich die Häufelkörper des Dammkulturgerätes (Wildhagen, 2003).

Abbildung 10: Tiefenlockerer nach Turiel zum Einsatz gegen Bodenverdichtungen (Brandt, 2003).

3 CO_2 evolution from a ridge tilled and a mouldboard ploughed Luvisol in the field

Evelyn Müller [1*], Holger Wildhagen [1], Michael Quintern [1], Jürgen Heß [2], Florian Wichern [3], Rainer Georg Joergensen [3]

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[1] Department of Soil Science, University of Kassel, Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany

[2] Department of Organic Farming and Cropping, University of Kassel, Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany

[3] Department of Soil Biology and Plant Nutrition, University of Kassel, Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany

Abstract

This field study was initiated to measure soil CO_2 evolution of the Turiel ridge tillage system under faba bean (*Vicia faba* L.) compared with mouldboard ploughing. The CO_2-C measurements were done *in situ* with a transportable infrared gas analyzer at different positions on the ridges and furrows and on mouldboard plough plots with and without vegetation, respectively. The CO_2 evolution at different ridge positions reflected a ridge pattern with a CO_2-C evolution in the order crown > shoulder > furrow. On a hectare basis the mouldboard ploughed soil evolved 0.11 t more CO_2-C ha^{-1} than ridges, and the plots with vegetation evolved 0.58 t more CO_2-C ha^{-1} than the plots without vegetation during the investigation period of 57 days. Soil temperature tended to be higher, and lower values tended to be lower on ploughed plots compared with ridge plots. The CO_2 evolution on the

* Corresponding author. Tel.: + 49 5542 98 1518; e-mail: emueller@mail.wiz.uni-kassel.de

planted plots decreased with time, reflecting the decreasing physiological activity of the plant roots. Overall, despite a high degree of soil disturbance, the amount of CO_2 evolved from the ridge tilled soil was lower compared to mouldboard plough tillage, probably reflecting less favorable conditions for soil microorganisms in the ridges compared to the ploughed soil.

Keywords: CO_2 evolution, ridge tillage system of Turiel

3.1 Introduction

Depending on their intensity, tillage systems cause gaseous losses in the form of CO_2 (Ellert and Janzen, 1990, Reikosky and Archer, 1997; Paustian et al., 2000). Studies have been conducted on conventional mouldboard ploughing (Franzluebbers et al., 1995; Ball et al., 1999; Aslam et al., 2000; Chatskikh and Olesen, 2007; Oorts et al., 2007, Yang et al., 2008), reduced tillage (Chatskikh and Olesen, 2007; Wright et al., 2008), no tillage (Franzluebbers et al., 1995; Ball et al., 1999; Aslam et al., 2000; Six et al., 2004; Frank et al., 2006; Chatskikh and Olesen, 2007; Oorts et al., 2007, Yang et al., 2008) and ridge tillage (Liebig et al., 1995). The ridge tillage system is characterized by ridges that are formed with sheets of metal, rollers or ridgers. In the permanent system, the ridges remain in the same position for years, being sculpted and mounted again during sowing. In the annual system, like the ridge tillage system of Turiel, the ridges are rebuilt every year in the previous year's furrow at sowing. Due to the domed form, the ridges provide earlier warmth of the soil in spring (Benjamin et al., 1990), and lower bulk density (Pikul Jr. et al., 2001). Moreover, the ridges have an influence on soil water supply (Bargar et al., 1999).

The soil organic C content is a broader parameter, referring to the carbon occurring in the soil organic material, which includes all organic constituents of the soil, like residues of dead plants or animals, products of their decomposition and soil microbial biomass. Changes in the soil organic C content occur very slowly (> 5 years) (Smith, 2004) and are very difficult to measure due to the spatial variability (Burton et al., 2006; Mueller and Koegel-Knabner, 2008). Therefore, the soil

organic C is not an appropriate instrument for measuring actual changes in the carbon stock under different tillage systems shortly after their introduction.

A more readily reacting indicator is soil microbial biomass C (Jenkinson and Ladd, 1981; Powlson and Brookes, 1987), which is responsible for the regulation of nutrient cycling and energy flow in soil (Jenkinson and Ladd, 1981; Wardle, 1998). However, changes in microbial biomass C also often need a considerable amount of time before they are statistically significant (Stockdale and Brookes, 2006).

Another, much faster method for estimating the carbon lost is the direct measurement of the soil CO_2-C evolution rate (Magid et al., 1997). CO_2 evolution from soils is linked to microbial turnover and activity as well as to the physical accessibility of organic material to microbes (Paustian et al., 2000). It is a product of root respiration of plants as well as of the decomposition of soil organic matter and crop residues by microbial organisms (Paul et al., 1999; Raich and Mora, 2005; Kuzyakov, 2006). This fact leads to the major problem of the *in situ* measurement of CO_2 evolution, because a differentiation into root respiration and respiration due to the microbial activity by decomposition of organic material is not possible. A further disadvantage is the diurnal dynamic of CO_2 evolution and the dependence on dry weather (Parkin and Kaspar, 2003; Steenwerth and Belina, 2008). Using a relative small chamber, it is possible to investigate even sinusoidal forms like ridges, where strong spatial heterogeneity was expected (Liebig et al., 1995). Measuring the CO_2 evolution of soils is an appropriate method for measuring the tillage induced impact on soil ecosystems and helps to understand short-term variability in CO_2 evolution (Parkin and Kaspar, 2003; Wichern et al., 2004). Furthermore, direct field measurements of gas exchange may lead to improved management practices and decreased C loss from soils (Reikosky et al., 2008).

Therefore, the present study was initiated: (1) to quantify CO_2 evolution for the ridge till system of Turiel and a conventional mouldboard ploughing system *in situ*, (2) to investigate the spatial variability of CO_2 evolution and soil temperature on the ridges, and (3) to determine the CO_2 evolution at different growth stages of faba bean.

3.2 Material and methods

3.2.1 Study site

The experimental site “Lindenbreite” is located at the research station of the University of Kassel, Frankenhausen in northern Hesse (51°24´ N, 9°25´E, 248 m a.s.l.). The mean annual temperature is 8.5 °C and the mean annual rainfall 650 mm. In 2007, total annual rainfall was 932 mm. During the experimental period in 2007 (June to August), precipitation was 169 mm and mean temperature was 16.7 °C, ranging from 12 °C to 25 °C (Fig. 11). The soil was a loess-derived Haplic Luvisol with 2 % sand, 81 % silt and 17 % clay at 0-30 cm depth. The pH ($CaCl_2$) was 6.9. Soil organic C and total N were 1.1 % and 0.1 %, respectively. The experimental site had a slope of about 5 % in south eastern direction.

The field experiment was established in 2002 with the objective of comparing alternative tillage systems. The tilling systems are ridge till by Turiel, the shallow mouldboard ploughing Ecomat-system down to 7 cm of Kverneland, and conventional mouldboard ploughing down to 25 cm. The field trial consisted of 36 plots with an area of 2.85 ha. Ridged plots were 15.3 x 35 m (the ridge width was 90 cm), the other plots were 12 x 35 m. The field trial was conducted as a completely randomized block design with four replicates and two factors (tillage system and crop). Crop rotation was biennial grass-clover followed by wheat, intercrop (green manure), potato, intercrop (green manure), faba bean and barley. In 2007, the investigated crop was faba bean (*Vicia faba* L.). Faba bean was sown on 4 April on ploughed plots and on 14 April on ridged plots, with 50 germinable grains m^{-2}, respectively.

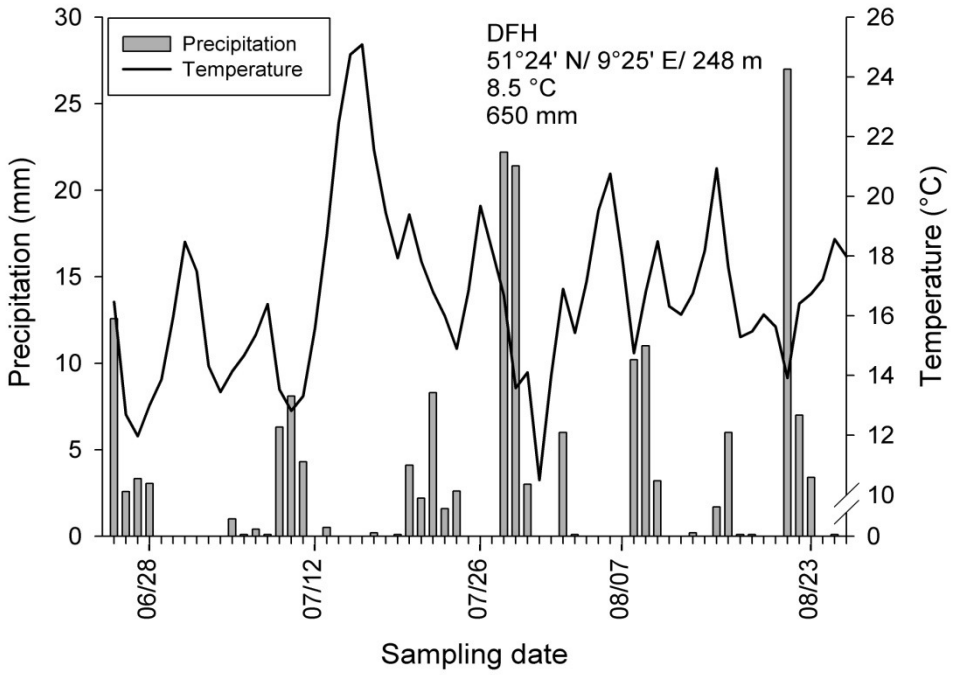

Figure 11: Climatic conditions during sampling time at the study site at Hessian state domain Frankenhausen (DFH).

3.2.2 Field measurements

Soil respiration was measured with the transportable infrared gas analyzer CIRAS-1 (Combined Infrared Gas Analysis System; PP Systems, Hitchin, UK). The analyzer consisted of a cylindrical chamber (10 cm diameter, 1.1 l volume), an infrared gas analyzer with a data logger and a sensor for measuring soil temperature at 5 cm soil depth. Previous to each measurement, the analyzer was calibrated with ambient air. After placing the chamber on undisturbed (no cracks, no plant material, no animals) soil surface, the CO_2-enrichment in the chamber was measured for 120 sec. Measurements were taken beneath the vegetation and on bare soil on eight plots with faba bean between 28 June and 23 August 2007. Bare soil plots were established by clearing vegetation from four squares in ploughed plots (50 x 50 cm) and on ridges (25 x 50 cm). On the ridges, measurements were taken on west furrows (F1; F3), west shoulders (S1; S3), crowns (Cr1; Cr2), east shoulder (S2; S4) and east furrow (F2; F4) (Fig. 12). On the ploughed plots, measurements were taken on plane squares. Measurements were taken on 27 June, 11 July, 6 August, and 22

August between 8 and 11 a.m. after rain and at the same position. The mean soil water content was 17%. The evaluation of phenological growth stages of faba bean plants was done according to Meier (2001) (Table 2).

Table 2 BBCH code and phenological growth stages for faba bean (*Vicia faba* L.).

	Date	BBCH Code	Phenological growth stages
Ploughed plots	28.06.	71	10% of pods have reached final length
	12.07.	75	50% of pods have reached final length
	26.07.	79	Nearly all pods have reached final length
	07.08.	86	60% of pods ripe and dark, seeds dry and hard
	23.08.	95	50% of stems brown or black
Ridged plots	28.06.	69	End of flowering
	12.07.	73	30% of pods have reached final length
	26.07.	77	70% of pods have reached final length
	07.08.	84	40% of pods ripe and dark, seeds dry and hard
	23.08.	93	Stems begin to darken

3.2.3 Estimation of surface size

For calculating the cumulated CO_2 evolution over the measuring period, the surface sizes and the different CO_2 evolution of each position on the ridges had to be considered. The ridges had bulges, which enlarged the surface size. The data of the CO_2 evolution measured with the IRGA was based on a plane soil surface. Therefore, the soil surface of 1 ha ridged arable land was recalculated on the basis of the real soil surface length, named “real distance”, on vegetated and non-vegetated ridges (Fig. 12).

The mean surface length of the ridges was 98 cm without vegetation and 94 cm with vegetation (n = 32). The CO_2 measurements with the IRGA were taken along this ridge line. Because every position showed different values of CO_2 evolution, the surface of the ridges was separated into areas with same evolution rates and known size. For this reason, one ridge had five areas of measurement (F, S, Cr, S, F) with a diameter of 10 cm (Table 3). However the diameters of the furrows (F) had to be corrected to 5 cm each because only half of the furrow belonged to a certain measuring ridge.

Consequently, just 40 cm of 98 cm without vegetation and 94 cm with vegetation were directly covered by the chamber. Between the five areas of measurement, four interspaces were left on one ridge. Hence, left lengths of 58 and 54 cm were distributed over four interspaces, with 14.5 cm on ridges without vegetation and 13.5 cm on ridges with vegetation, respectively. On average, 111 ridges of 90 cm width and a length of 100 m were present on a one hectare field. Consequently, the whole surface area of a one hectare area of ridges without vegetation was 10,878 m² and 10,434 m² for ridges with vegetation. Therefore, the soil surface of a one hectare area of ridged fields was 9%, i.e. 4% higher than one hectare of ploughed arable farmland.

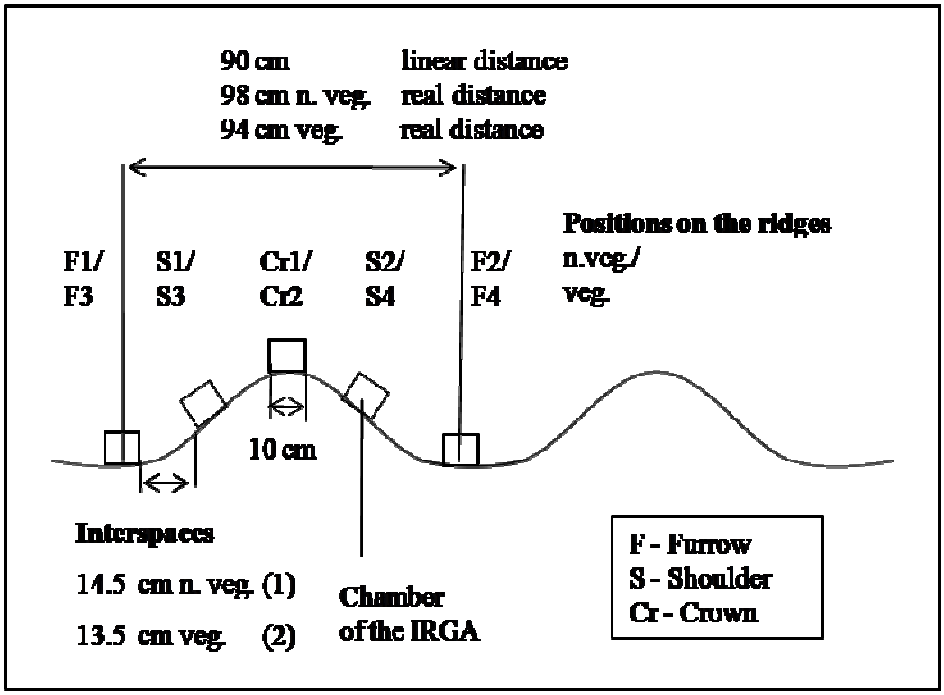

Figure 12: Ridge-scheme as profile with dimensions for calculating soil surface on ridges without vegetation (n. veg.; (1); 98 cm; n = 32) and ridges with vegetation (veg.; (2); 94 cm; n = 32) according to measurements taken on the plots. F is furrow; S and Cr stand for shoulder and crown.

3.3 Results

The vegetation on the ploughed plots showed a more rapid phenological development than that on ridge till plots at each sampling date (Table 2, Fig. 15). The mean soil temperature was 0.1°C higher on the ridges than on ploughed plots during the experimental period, with higher values on the bare plots than on the planted plots (Fig. 13). On the planted ridges, the soil temperature varied less between the different positions than on the bare ridges, where differences of up to 1°C occurred between the different positions. The highest CO_2 evolution rate of 7.05 g m^{-2} $d^{-1}$was measured on the ploughed plots with vegetation on 28 June and declined during the experimental period in both tillage systems, reaching a plateau in August (Fig. 14). The differences in CO_2 evolution between planted and bare plots decreased with time (Fig. 14). Also the difference in CO_2 evolution between the positions on the ridge decreased with time (Fig. 15).

On the planted ridges, highest CO_2 evolution rates were observed at position Cr2 followed by the positions S3, S4, F4, and F3. On the planted ridges, the CO_2 evolution pattern followed the shape of the ridge, with the highest evolution rates on the crown decreasing down on shoulders and furrows (Fig. 15, Table 3). On the bare ridges, the maximum evolution rates were measured at position S2, followed by crown, shoulder and furrows (Fig. 15, Table 3). The ploughed plots evolved 0.11 t CO_2-C ha^{-1} 57 d^{-1} or 9% more CO_2-C than the ridged plots, and the planted plots evolved 0.58 t CO_2-C ha^{-1} 57 d^{-1} or roughly 60% more CO_2-C than the bare plots (Table 3).

Table 3 Sum of the CO_2-C evolution of one hectare ridged and ploughed arable farm land for the measuring period of 57 days.

		CO_2-C ($t\ ha^{-1}\ 57\ d^{-1}$)	CO_2-C ($t\ ha^{-1}\ 57\ d^{-1}$) (plane surface)
Plough	without veg.	1.04	1.04
	with veg.	1.62	1.62
Ridges without veg.	**Furrow 1**	0.35	
	Interspace 1a	1.15	
	Shoulder 1	0.90	
	Interspace 1b	1.34	
	Crown 1	0.95	
	Interspace 1c	1.56	
	Shoulder 2	1.20	
	Interspace 1d	1.34	
	Furrow 2	0.33	
	Mean	1.01	0.93
Ridges with veg.	**Furrow 3**	0.46	
	Interspace 2a	1.64	
	Shoulder 3	1.52	
	Interspace 2b	2.47	
	Crown 2	2.14	
	Interspace 2c	2.41	
	Shoulder 4	1.42	
	Interspace 2d	1.64	
	Furrow 4	0.50	
	Mean	1.58	1.51

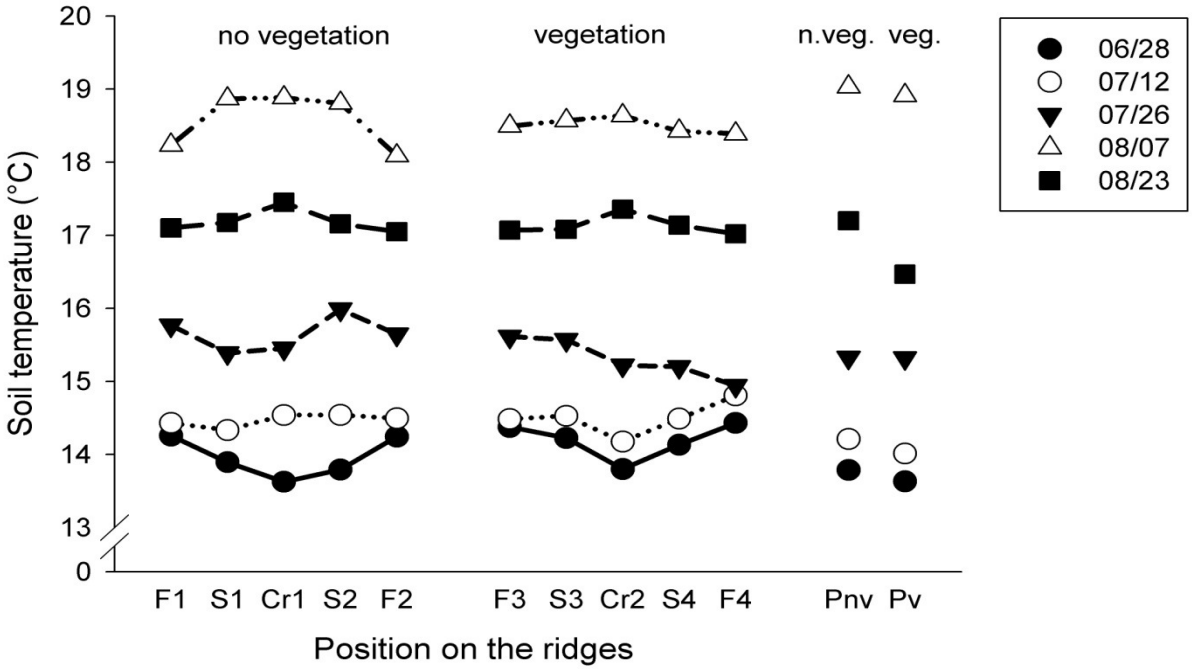

Figure 13: Soil temperatures at 5 cm depth at location of CO_2 measurement in faba bean *(Vicia faba* L.*)* at different positions on the ridges (F: furrow; S: shoulder; Cr: crown).

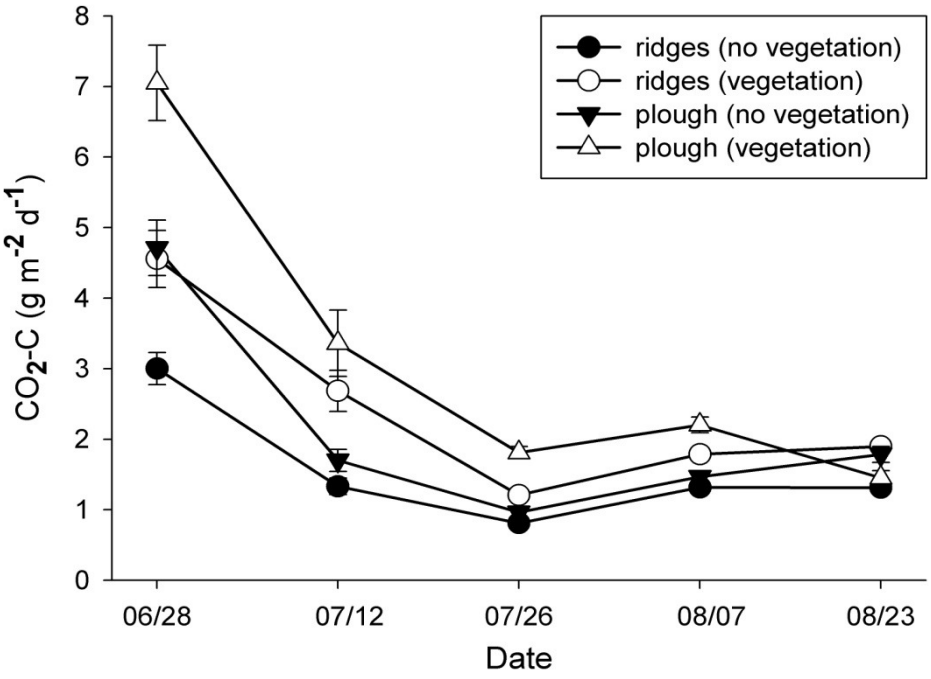

Figure 14: The CO_2 evolution rates (g CO_2-C m^{-2} d^{-1}) on ploughed and ridged plots with and without vegetation. Vertical bars show standard error of the mean (n = 16).

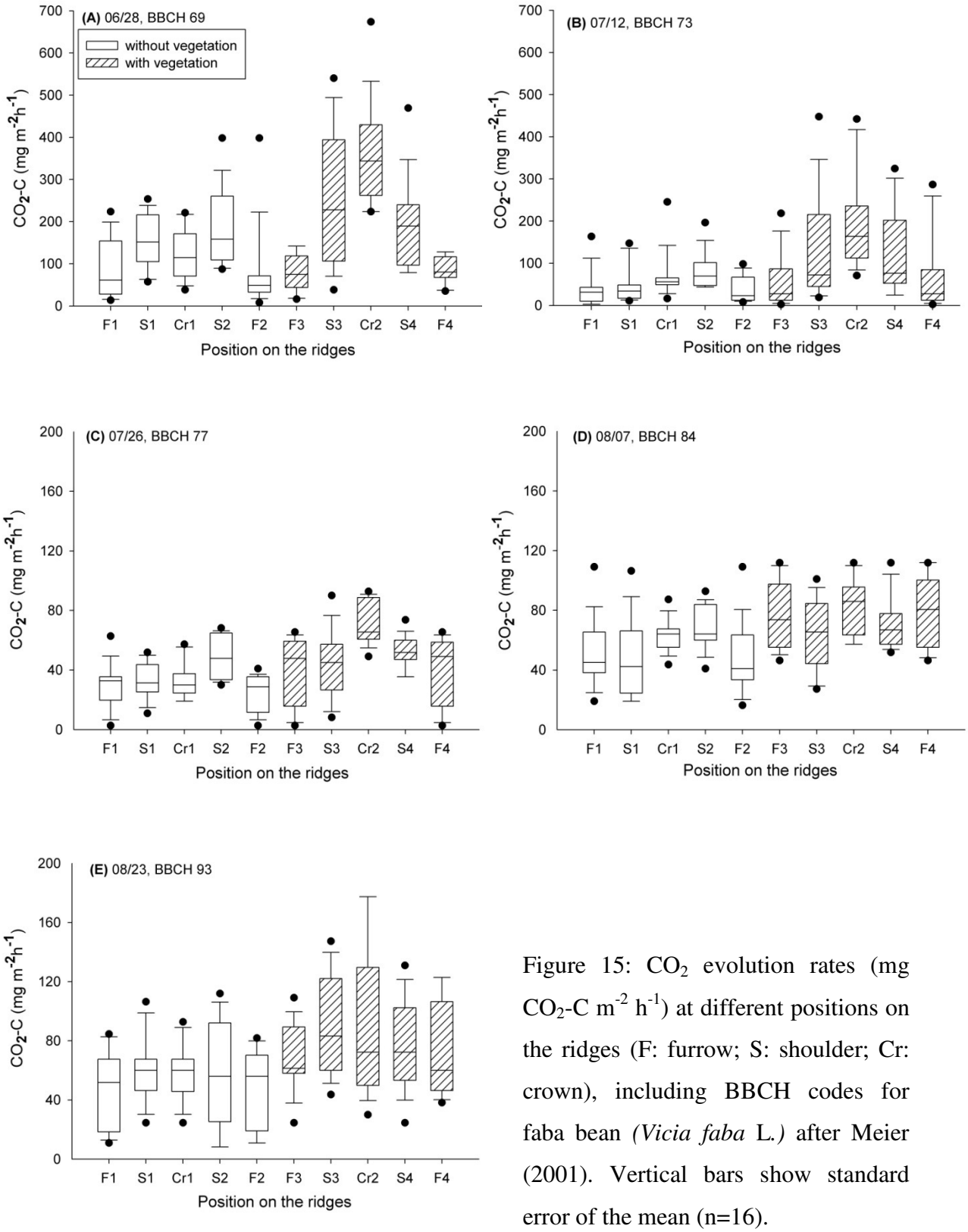

Figure 15: CO_2 evolution rates (mg CO_2-C m^{-2} h^{-1}) at different positions on the ridges (F: furrow; S: shoulder; Cr: crown), including BBCH codes for faba bean *(Vicia faba* L.*)* after Meier (2001). Vertical bars show standard error of the mean (n=16).

3.4 Discussion

The mouldboard ploughed plots evolved more CO_2 than the ridged plots over the whole experimental period. However, the difference in CO_2 evolution rate between these two systems was much smaller than that observed by Reikosky and Archer (2007), where the mouldboard ploughing system evolved a 3.8 times more CO_2 than the no-till system. Also Chatskikh and Olesen (2007) reported the highest CO_2 evolution rates in the ploughing system, which exceeded those of the reduced and direct drilling systems by 21 and 25%, respectively. Consequently, the soil CO_2 evolution rates of different tillage systems decreased in the order mouldboard ploughing > ridge tillage > reduced tillage > no tillage. These differences are caused by differences in (1) soil disturbance (Franzluebbers et al., 1995; Reikosky and Archer, 2007) and (2) residues distribution (Grigera et al., 2007) and by different effects on (3) vegetation and (4) microclimate (Vinther and Dahlmann-Hansen, 2005).

Increasing soil disturbance usually leads to increased CO_2 evolution rates depending on depth and volume of soil disturbed by tillage (Franzluebbers et al., 1995; Reikosky and Archer, 2007). It is well known, that the residue management has an influence on the availability of organic matter, the quantity of microorganisms and their activity (Doran et al., 1998; Frank et al., 2006). Due to the ridge formation, residue distribution was probably uneven in the ridges, explaining some of the variation in the data. In maize rows with plant residues, the CO_2-C evolution rate was considerably increased in comparison to rows without residues (John et al., 2004). The spatial heterogeneity is not only affected by the residue distribution, but also by differences in soil physical properties (Kaiser and Heinemeyer, 1993; Liebig et al., 1995). In an incubation experiment, highest CO_2-C evolution rates were measured in rows followed by non-trafficked interrows and trafficked interrows (Liebig et al., 1995). This ranking supported our findings on the differences in evolved CO_2-C between furrows and crowns. Moreover, we complemented those data with *in situ* measurements for the other positions of the ridges, to get substantial data for calculating cumulative CO_2 evolutions of the ridge tillage system.

Planted plots evolved nearly two-thirds more CO_2-C in comparison with bare plots as observed by others. Montheith et al. (1964) observed 50 to 75% increases in CO_2 evolution under vegetation in comparison with non-vegetated plots. Wichern et al. (2004) measured a 66% higher CO_2-C evolution on plots planted with wheat than on bare plots, Raich and Mora (2005) found 20% higher rates of soil CO_2 evolution on plots with maize (*Zea mays* L.) in comparison with bare plots. The total soil CO_2 evolution is a result of the soil respiration from decomposition of soil organic matter and crop residues and the root respiration of plants (Jensen et al., 1996; Raich and Mora, 2005; Oorts et al., 2007; Werth and Kuzyakov, 2008). The root respiration cannot be separated from respiration of root-derived compounds (rhizodeposits). Moreover, plant roots also influence CO_2-release from soil organic matter. In addition, also root biomass (Han, 2007) and root distribution (Kovar et al., 1992) had strong impacts on CO_2 evolution rates. According to Fu et al. (2002) and Werth and Kuzyakov (2008), the contribution of root-derived C to total soil CO_2 evolution depends on the plant species among many other factors, such as plant development.

The rough decrease of the CO_2 evolution rates from 28 June to 12 July and to a lower extent on 26 July, reflect the phenological change from vegetative to generative growth. This change is accompanied by a translocation of the main assimilates into the pods and the developing seeds (Wichern et al., 2007a). Our results confirm the observations of others who also reported a decline of root derived CO_2-C after flowering of e.g. soybean (Fu et al. 2002) and barley (Lohila et al., 2003). Therefore, the supply of easily degradable C to the microbial biomass in the rhizosphere decelerated (Wichern et al., 2007b). As a result, the soil CO_2 evolution rates decrease until the end of the growing season, which has also been reported previously (Rochette et al., 1999; Fu et al., 2002).

This decrease is also affected by the differences in soil temperatures on planted and on bare plots, for example by reduced variability of soil temperature on plots with vegetation. In our study, the soil temperature on ridged plots was lower than in ploughed plots, especially when the air temperature was high. This is in accordance with previous research by Johnson and Lowery (1985), Griffith et al. (1988), Kovar et al. (1992), who reported a 1°C higher soil temperature in ploughed plots

compared to ridged plots. The higher surface area enabled the soil to dry more rapidly and to lose more heat during the night (Vinther and Dahlmann-Hansen, 2005), resulting in lower CO_2 evolution rates (Franzluebbers et al., 1995). However, Vinther and Dahlmann-Hansen (2005) measured no significant difference between the average soil temperatures in ridges and in flat soil during the growing period from April to August, but documented a diurnal variation. At low air temperature, soil temperature in ridged plots tends to be higher in comparison to ploughed plots. Some variability of the soil temperature was probably caused by shading through plants of neighboring ridges.

Our measurements showed different soil CO_2 evolution rates at each position of the ridges on all plots. The main reason was probably the exposure of the ridge to solar radiation (Benjamin, 1990), the east-south direction of the ridges (Velten et al., 2003) as well as the wind speed and the wind direction on bare soil (McInnes, 1994). These differences in microclimate cause different microbial activities along the ridge. The maximum CO_2 evolution at position S2 in non-vegetated plots and Cr2 on vegetated ridges were mainly caused by the exposure of the ridge in southeastern direction where the ridges were warmed first by the sun. This is supported by the results of Buyanovsky and Wagner (1983), Orchard and Cook (1983), Rochette et al. (1992, 1999) and Fang and Moncrief (2001), who reported that soil respiration was strongly related to soil temperature and to soil moisture. McInnes (1994) reported the influence of wind speed and wind direction on aerodynamic conductance for heat of windward and leeward sides of ridges and differences between furrows and ridges. In the present field trial the prevailing wind direction is southwest, which probably explains the lower soil temperature and CO_2-C evolution on the western parts of the ridges on several days.

3.5 Conclusions

The higher CO_2 evolution on ploughed plots in comparison with ridge tilled plots was probably related to the higher turnover of soil organic matter within the plough layer, due to more stable living conditions for microorganisms. Concerning the amount of CO_2-C evolution, the ridge tillage system Turiel was placed between the

mouldboard ploughing system and the reduced tillage systems, followed by no-till. As a consequence of different microclimates and tillage-induced changes in physical, chemical and biological soil properties, spatial variability of CO_2-C evolution on ridges was observed.

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4 Soil CO_2 evolution rates in the field – a comparison of three methods

Evelyn Müller[1)*], Nils Rottmann[2)], Anja Bergstermann[3)], Holger Wildhagen[1)], Rainer Georg Joergensen[2)]

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1) Department of Soil Science, University of Kassel, Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany

2) Department of Soil Biology and Plant Nutrition, University of Kassel, Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany

3) Department of Soil Science of Temperate and Boreal Ecosystems, Büsgen-Institut,
University of Göttingen, Büsgenweg 2, 37077 Göttingen, Germany

Abstract

In this field study, three methods for determining soil CO_2 evolution rates were compared: (1) a static chamber method and (2) a dynamic chamber method, both with gas chromatographic (GC) analysis of air samples and (3) a dynamic chamber system using a portable infrared gas analyzer (CIRAS). The mean CO_2 evolution rate in the field increased in the order static chamber < dynamic chamber < CIRAS by 40%. The CO_2 evolution rates obtained by the three methods were significantly correlated. None of the three methods was significantly affected by soil moisture or soil temperature. However, air temperature had strong negative effects on the static and the dynamic chamber method with GC analysis of air samples. In conclusion, the CIRAS measurements provided most reliable data for soil CO_2 evolution rates.

* Corresponding author. Tel.: + 49 5542 98 1518; e-mail: emueller@mail.wiz.uni-kassel.de

Keywords: CO_2 evolution, static chamber, dynamic chamber, portable infrared gas analyzer

4.1 Introduction

Soil respiration is one of the main sources of CO_2 evolution in terrestrial ecosystems (Raich and Schlesinger 1992) and it shows an immediate response to changes in environmental conditions (Jensen et al. 1996; Wichern et al. 2004a; Müller et al. 2009). Therefore, an accurate estimation of CO_2 evolution in the field is important. A common measuring method is the placement of a chamber on the soil surface. In these chambers, the CO_2 evolved is measured directly in open systems or after CO_2 enrichment in closed systems.

The closed chamber systems can be divided into two subtypes according to the absence (static) or presence (dynamic) of airflow in the chamber (Witkamp and Frank 1969). In static chambers, the CO_2 evolved can be measured after absorption in NaOH solution (Jensen et al. 1996) or soda lime for 24 h (Lundegardh 1927, Edwards 1982) or by analyzing air samples with a gas chromatograph (Loftfield et al. 1997; Ludwig et al. 2006; Ruser et al. 2006). Absorption methods are cheap and allow large numbers of replicates (Janssens and Ceulemans 1998; Janssens et al. 2000). But they are less accurate, as they overestimate small evolutions and underestimate large evolutions (Nay et al. 1994, Jensen et al. 1996). However, 24-h coverage of the soil surface changes the microclimate, especially humidity and temperature (Le Dantec et al. 1999), influencing the soil CO_2 evolution rates (Orchard and Cook 1983, Blanke 1996). Another method for measuring CO_2 evolution in the chamber is sampling of the headspace air at specific time intervals, followed by a gas chromatographic measurement in the laboratory. This method has been intensively used for measuring N_2O evolutions (Flessa et al. 1995; Ruser et al. 2001). Sampling in the field needs some additional work for installing pipes, but sample analysis with a gas chromatograph (GC) is cheap and available in many laboratories. A drawback of this method is the need to measure 4 - 5 air samples to

get one value. This is due to the calculation, which uses an increase in CO_2 concentration at different intervals (0, 10, 20, 30 min) after closing the chamber.
The static chamber method with GC analysis can be transformed into a dynamic method by installing an additional fan module to reduce the development of a laminar layer at the bottom of the chamber. Such dynamic systems are often connected to a portable infrared gas analyzer (Bekku et al. 1995; Wichern et al. 2004b), which allows direct measurements in the field over short sampling times of up 120 sec. These short periods have the advantage that changes of soil temperature and soil moisture are too small to affect CO_2 evolution rates (Janssens et al. 2000) and that measurements can be carried out in high temporal and spatial distribution (Scheuner et al. 2003; Terhoeven-Urselmans et al. 2009). However, this portable dynamic chamber method has been shown to underestimate CO_2 evolution rates in pot experiments at very high rates (Muhammad et al. 2007a, b). Also, Jensen et al. (1996) reported 12% higher CO_2-C evolution rates of static chambers with NaOH absorption in comparison with the portable dynamic chamber method. As no standard procedures or calibration methods exist for determining CO_2 evolution rates in the field, the objective of the present study was to compare three different approaches for gas measurements. The aim was to evaluate their usability for determining *in situ* CO_2-C evolution rates.

4.2 Material and Methods

Study site

The field experiment was carried out on the experimental farm of the University of Göttingen. The Reinshof is located 8 km south of Göttingen in Lower Saxony/Germany (51°29.3´ N, 9°56.2`E, 165 m a.s.l.) The study site was “Garte Süd”, which had been cultivated with conventional tillage and minimum tillage since 1970. The field trial consisted of 16 plots divided in four blocks. The first and most western plot in every block had a width of 18.5 m, the three other plots of 20 m. All plots had a length of 40 m. The total area of the field trial was 1.4 ha. Our measurements took place on four plots, one per block, managed with conventional

tillage. The mean annual rainfall is 645 mm, with a mean annual temperature of 8.7°C. During the investigation period in 2008, the precipitation was 177 mm and the mean temperature was 17°C, with a maximum at 25°C and a minimum of 7°C. The soil was classified as Haplic Luvisol according to the FAO classification system. At 0-30 cm, the soil contained 15% clay, 73% silt, and 12% sand (Ehlers et al. 2000), with a pH in $CaCl_2$ of 7.1 and contents of 0.94% soil organic carbon and 0.11% total nitrogen (Reiter et al. 2002). In September 2007, the experimental site was mulched, followed by ploughing at 25 cm depth, rotary harrowing at 8 cm depth, and sowing of winter wheat (*Triticum aestivum* L.) in November 2007. Winter wheat was harvested on 31 July 2008 and the plots were rotary harrowed on 15 August 2008.

Field measurements

Measurements were carried out on 1, 3, 4, 9, 10 and 11 September 2008, between 8 a.m. and 1 p.m. For determination of the soil water content, samples were taken at 0-10 cm depth. Soil temperature was measured at 5 cm soil depth. Plants were removed from the sampling areas. For the static chamber method, three PVC pipes per plot, with distances of 2 to 20 m were installed in the field trial on 18 August 2008 and pressed 12 cm into the soil. Each pipe had a PVC end cap with an air sampling port including a rubber septum and an additional silicon tube for equalization of pressure during chamber closing. The pipes with end caps had a diameter of 29.5 cm and a height of 28 cm measured from soil surface. The volume was 19.1 l and the size of the area 683.5 cm^2. For sampling, the cap was put on top of the pipe and the contact line was sealed with a rubber collar. The soil air samples were taken with a steel cannula (13 cm length), which was attached through silicon tubes with an evacuated 100 ml gas mouse. Before sampling, the silicone tubes were evacuated with a hand pump. The intervals of the measurements were: at the beginning (0 min), after 10, 20 and 30 minutes. Four air samples were taken per plot and PVC pipe. They were analyzed with a gas chromatograph GC-14B (Shimadzu Corporation, Kyoto, Japan). The four measurements per pipe, which show the enrichment in CO_2 concentration during the measuring period (30 min), were used

to calculate the gradient of the enrichment curve. The CO_2-C evolution rates (mg m² h^{-1}) were calculated from the gradient, the volume and the enclosed soil surface area of the chamber as well as the air temperature. Three calculated values were used to generate the mean CO_2 evolution per plot. For each measuring day (6), four values (4 plots) were calculated (n = 24).

For the dynamic chamber method, the PVC pipes with end caps of the static chamber method were used. Additionally a fan-module was installed in the pipes before sampling. The module consisted of a brushless fan (Akasa, DFS802512L; 8 x 8 x 2.5 cm) with a circulation power of 64 m³ air h^{-1}. The fan was fixed at a height of 22 cm by four thread rods (25 cm length) and connected to a 9 V block battery. The module was switched on and the thread rods were pressed 2 cm into the soil next to the centre of the pipe, avoiding collision with the cannula. The sampling procedure, the sampling interval, the analyzing apparatus and the calculations were the same as in the static chamber method.

The third measuring method is the measurement of CO_2 evolution with the portable gas analyzer CIRAS-1 (Combined Infrared Gas Analysis System, PP Systems, Hitchin, UK). The analyzer consisted of a cylindrical chamber (height = 15 cm, diameter = 10 cm, volume = 1.1 l, area = 78.5 cm²), with a small fan, connected to the gas analyzer with a data logger and a probe for measuring soil temperature (Blanke 1996). Because of the built-in fan, which circulated and vacuumed-in the soil air, the CIRAS is also a dynamic chamber system. For the CO_2-C measurements, the steel ring at the bottom of the cylindrical chamber was pushed about 2 cm into bare, undisturbed soil. In the chamber, CO_2 enrichment began and was measured for 120 sec. Before the first and after each measurement the CIRAS calibrated itself with ambient air. Three measurements was taken per plot (one per PVC pipe) and their mean was calculated per plot for each sampling day (n = 24). The measurements were taken in close proximity to the PVC pipes. Sampling positions were marked and used again next measuring day.

Statistical analysis

The significance between the measuring methods was tested by a one-way analysis of variance (ANOVA). Post hoc comparisons were made using Tukey/Kramer HSD test ($p < 0.05$). Pearson correlation with additional pair wise correlation was used to determine relationships between the measuring methods and the soil water content and soil and air temperature. All statistical analyses were performed using JMP 7.0 (SAS Institute Inc., Cary, USA).

4.3 Results

During the investigation period, the mean soil water content was 15%, the soil temperature was 16°C and the mean air temperature 18°C (Table 4). The soil water content increased and the soil temperature decreased in the first investigation period from 1 to 4 September (Fig. 16). In the second period from 9 to 11 September, the soil temperature increased, whereas the soil water content decreased.

The mean CO_2 evolution rate in the field significantly increased in the order static chamber < dynamic chamber < CIRAS by 40% (Table 4). The CO_2 evolution rates obtained by the three methods were significantly correlated, despite the differences between the means and the large variation of 19 and 36% between the replicate measurements within one method. None of the three methods was significantly affected by soil moisture or soil temperature. However, air temperature had strong negative effects on the static and the dynamic chamber method. Air temperature was reflected by soil temperature, but on a lower level with higher variability. The CO_2 evolution rates of these two methods strongly declined over the last three sampling days (Fig. 17), when air and soil temperature increased. In contrast, the CO_2 evolution rates obtained by CIRAS remained more or less constant throughout the experimental period.

Table 4 Mean values of CO_2 evolution (n = 24), soil moisture (n = 24), soil temperature (n = 24) and air temperature (n = 6). Pearson correlation coefficients between the different methods for measuring soil CO_2-C evolution, the soil water content and the soil and air temperature.

	Static chamber	Dynamic chamber	CIRAS	Soil moisture	Soil temperature	Air temperature
	($g\ CO_2\text{-}C\ m^{-2}\ h^{-1}$)			(%)	(°C)	
Mean	60 b	71 ab	83 a	15	16.0	16.4
CV (±%)	36	36	19	5	5	13
Correlation coefficients						
Static chamber		0.69**	0.38^{+}	0.09	-0.33	-0.67**
Dynamic chamber			0.52*	0.11	-0.37	-0.72**
CIRAS				-0.19	-0.19	-0.3
Soil moisture					-0.33	-0.06
Soil temperature						0.17

$^{+}$ $p \leq 0.10$, * $p \leq 0.05$, ** $p \leq 0.01$; n = 24; CV = mean coefficient of variation between replicate measurements; different letters within row indicate a significant difference between the methods for measuring the CO_2 evolution rate ($p < 0.05$, Tukey/Kramer n = 24).

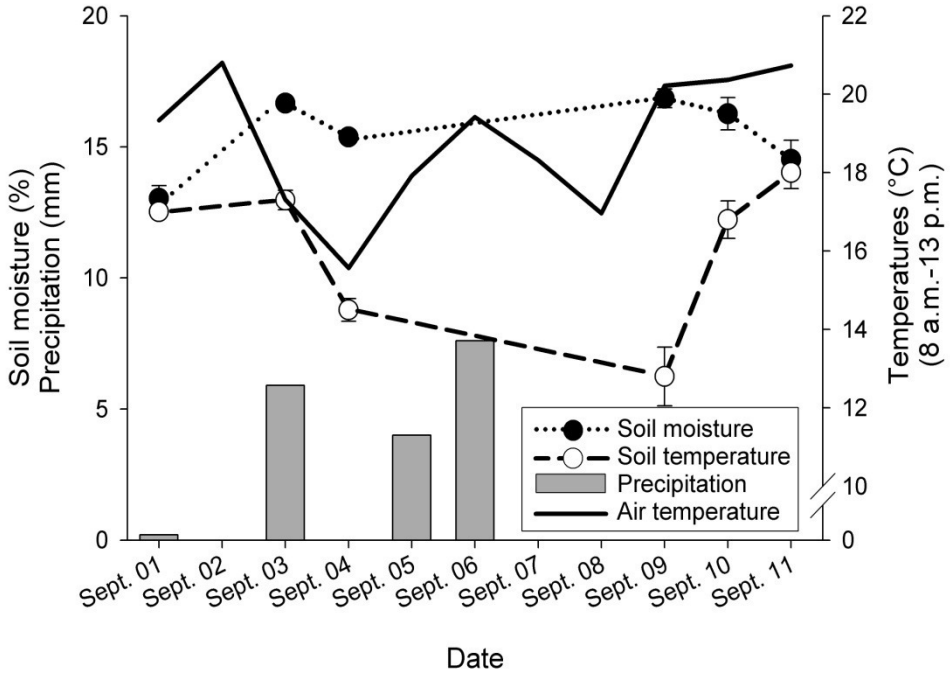

Figure 16: Precipitation, the soil moisture (0-10 cm), the air and the soil temperature (5 cm soil depth; between 8 and 13 a.m.) at "Garte Süd" during investigation period in 2008. Vertical bars show standard error of the mean (n = 4).

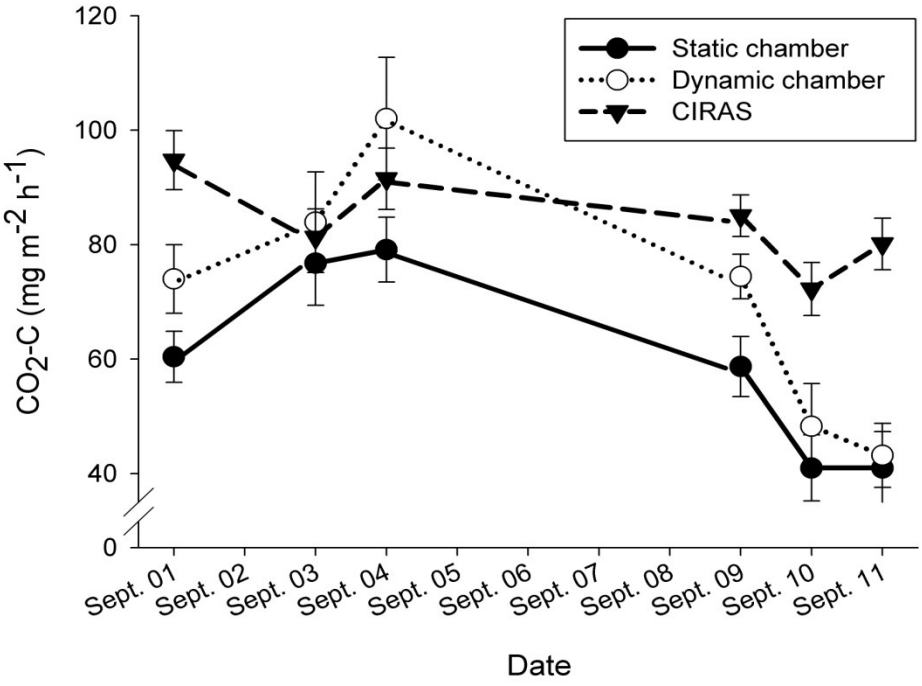

Figure 17: The soil CO_2-C evolution rates (mg CO_2-C m^{-2} h^{-1}) for the *in situ* measuring methods at "Garte Süd" during investigation period in 2008. Vertical bars show standard error of the mean (n = 24).

4.4 Discussion

The measured CO_2-C evolution rates were equivalent to 9.8 to 24.5 kg CO_2-C ha^{-1} day^{-1}. They were generally in the lower and mid part of the range obtained by Franzluebbers et al. (1995) reporting an average of 25.2 kg CO_2-C ha^{-1} day^{-1}, by Frank et al. (2006) observing an average of 19.0 kg CO_2-C ha^{-1} day^{-1}, and by Oorts et al. (2007) measuring 9.5 kg CO_2-C ha^{-1} day^{-1}.

A high coefficient of variation between the replicate measurements was also found by Jensen et al. (1996) and may have been caused by differences in amount and distribution of plant residues during rotary harrowing (Oorts et al. 2007). High spatial heterogeneity of the CO_2 evolution rate is often caused by differences in soil moisture and soil temperature (Wichern et al. 2004a; Reth et al. 2005; Frank et al. 2006). Buyanovsky and Wagner (1983) calculated that soil moisture and soil temperature were responsible for more than 50% of the variation in CO_2 evolution. In the present study, no direct effects of soil moisture or soil temperature were found on any of the three methods, due to their reverse relationship over the experimental period.

The CIRAS measured the highest CO_2-C evolution rates compared to the other methods. The installed fan ensured a permanent satisfactory mixture within the relatively small chamber, which is absolutely necessary for correct CO_2 measurements (Pumpanen et al. 2004). The possibility that the wind speed in the CIRAS chamber might exhaust the soil of CO_2, especially in very dry soil, has been mentioned repeatedly (Hanson et al. 1993; Norman et al. 1997; Le Dantec et al. 1999). However, Kimball and Lemon (1971) did not find significant effects of wind speed on CO_2 evolution rates above a silt loam. Others have stated that the wind speed in dynamic chambers is too low to cause significant effects on CO_2 evolution rates (Edwards and Sollins, 1973, Cropper et al. 1985, Keith and Wong 2006). Another reason for incorrect estimation of CO_2 evolution rates might be an insufficient equilibration with atmospheric pressure during positioning of the chamber (Le Dantec et al. 1999; Lund et al. 1999). However, Janssens et al. (2000) was unable to detect any pressure gradient for the CIRAS system between the chamber headspace and the ambient air.

In static chambers, the air is not moved and CO_2 evolution is caused by diffusion along a gradient in concentration (Kimball 1983). This gradient is decreased by trapping CO_2 in closed chambers, forming layers with increasing concentration due to the high density of CO_2. This results in lateral flow from below to the area surrounding the chamber, leading to lower CO_2 rates (Janssens et al. 2000). Therefore, static chambers with GC analysis of air samples might underestimate the soil CO_2 evolution rates in the field (Norman et al 1997). This problem is intensified by the size of the chambers, which is probably the main reason for strong negative relationships between air temperature and CO_2 evolution rates obtained by static and dynamic chamber methods with GC analysis of air samples at the end of the experimental period. With increasing temperature, the pressure in the chamber most likely increased, reducing the efflux of air into the chamber (Lund et al. 1999). The fan-module apparently decreased the boundary layer in the bottom of the chamber (Janssens et al. 2000), but did not eliminate the negative impact of air temperature.
In conclusion, the CIRAS measurements provided most reliable data for soil CO_2 evolution rates in the field compared to the dynamic and the static chamber method with GC analysis of air samples. Additionally, the sampling is relatively time consuming and analyzing the air samples in the laboratory needs further efforts. In contrast, the CIRAS handling is very simple under field conditions.

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5 Spatial patterns of soil biological and physical properties in a ridge tilled and a ploughed Luvisol

Evelyn Müller [1*], Holger Wildhagen [1], Michael Quintern [1], Jürgen Heß [2], Florian Wichern [3], Rainer Georg Joergensen [3]

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[1] Department of Soil Science, University of Kassel, Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany

[2] Department of Organic Farming and Cropping, University of Kassel, Nordbahnhoftr. 1a, 37213 Witzenhausen, Germany

[3] Department of Soil Biology and Plant Nutrition, University of Kassel, Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany

Abstract

The present study was conducted to determine the spatial heterogeneity of bulk density, soil moisture, inorganic N, microbial biomass C, and microbial biomass N in the ridge tillage system of Turiel compared to conventional mouldboard ploughing on three sampling dates in May, July, and August. The soil sampling was carried out under vegetation representing the ridge in a high spatial resolution down the soil profile. Bulk density increased with depth and ranged from 1.3 g cm^{-3} at 10 cm depth to 1.6 g cm^{-3} at 35 cm in ploughed plots and from 1.0 g m^{-3} at 5 cm to 1.4 g m^{-3} at 35 cm in the ridges. In the ploughed plots, the contents of microbial biomass C and microbial biomass N remained roughly constant at 215 and 33 µg g^{-1} soil, respectively, throughout the experimental period. The microbial biomass C/N ratio varied in a small range around 6.4. In the ridged plots, the contents of

* Corresponding author. Tel.: + 49 5542 98 1518; e-mail: emueller@mail.wiz.uni-kassel.de

microbial biomass C and microbial biomass N were 5% and 6% higher compared to the ploughed plots. Highest microbial biomass C contents of roughly 300 µg g^{-1} soil were always measured in the crowns in July. The lowest contents of microbial biomass C of 85 to 137 µg g^{-1} soil were measured in the furrows. The ridges showed strong spatial heterogeneity in bulk density, soil water content, inorganic nitrogen and microbial biomass.

Keywords: Turiel, bulk density, microbial biomass C, microbial biomass N

5.1 Introduction

Tillage systems have to fulfil several main purposes in modern agriculture. Primarily, they loosen the soil and incorporate plant residues or other amendments. In the best case, tillage management prepares an optimum seed bed for germination and further crop growth (Pikul Jr. et al., 2001). Furthermore, tillage system should minimize erosion and pathogens (Henriksen et al., 2007) and provide an optimum weed control, which is especially important in organic agriculture (Dick, 1997). Tillage systems differ according to their invasion depth and intensity (Paul et al., 1999), their residue distribution (Kandeler et al., 1999), their impact on soil water supply, aeration, and soil biota (Franzluebbers et al., 1995; Liebig et al., 1995, Dick, 1997; Limon-Ortega et al., 2002). An essential precondition for sustainable agriculture is a knowledge of these tillage induced impacts on the soils (Rahman et al., 2008).

The mouldboard ploughing system is the most common agricultural tillage system in the world. The advantages are e.g. deep loosening of the soil, incorporation of plant residues into deeper layers, mechanical weed control and a homogeneous plane seed bed (Håkansson et al., 1998). Disadvantages are the development of plough pans with high bulk density, resulting in poor conditions for C and N mineralization (Reicosky and Archer, 2007), as well as high inputs of fuel and workload.

The ridge tillage system is not as common but is also established throughout the world. In general, the ridges are formed with sheets of metal or rollers and the ridges stay in the same position in the field for years and are mounted again in the following spring (Benjamin et al., 1990). Permanent ridges provide a better water (Benjamin et al., 1990) and temperature environment (Bargar et al., 1999) for plant emergence and further plant growth, compared to flat soil surfaces. A lower bulk density has additional positive effects on root growth (Liebig et al., 1993; Pikul Jr. et al., 2001). In Germany, the ridge tillage system is mainly used for potato (*Solanum tuberosum*) cultivation due to facilitated harvest. However, the ridge tillage system can also be used for cereals, legumes or vegetables (Tisdall and Hodgson, 1990; Borin and Sartori, 1995; Nokes et al., 1997). The positive attributes have resulted in a growing interest in ridge tillage, especially in organic agriculture. In the tillage system of Turiel, the ridges are formed with a ridger and stay on the field from sowing to harvest of the crop. They are reformed in the next year on the former furrow positions. The question is whether some of the positive attributes of the permanent ridge tillage system can be integrated into that of Turiel, resulting in better conditions for plant emergence and further growth, compared to the mouldboard ploughing system. The objective was to study the spatial patterns of soil biological and physical properties down the profile at different positions of the ridges in the Turiel tillage system in comparison with a conventional mouldboard ploughing system.

5.2 Material and methods

5.2.1 Site description and experimental design

The research was conducted on the experimental site “Lindenbreite” at the Hessian State Domain Frankenhausen in northern Hesse, Germany (51°24´ N, 9°25´ E, 248 m a.s.l.). Samples were taken on 16 May, 10 July, and 20 August 2007. During the experimental period, precipitation was 366 mm and mean temperature was 16.6°C, ranging from 4°C to 25°C. The total annual rainfall was 932 mm in 2007. The mean annual rainfall is 650 mm and the mean annual temperature 8.5°C. The soil was a

Haplic Luvisol on loess. The texture was 2% sand, 81% silt, and 17% clay at 0-30 cm depth. The pH ($CaCl_2$) was 6.8, soil organic C and total N were 1.1% and 0.1%, respectively.

The field experiment was established in 2002, comparing conventional mouldboard ploughing down to 25 cm depth with the ridge till system of Turiel and the shallow mouldboard Ecomat system of Kverneland (down to 7 cm). The present experiment is focused on a comparison of conventional mouldboard ploughing with the Turiel system. The field trial was carried out as a fully randomized block design with four blocks and the two factors tillage system and crop. The field trial consisted of 36 plots with a total area of 2.85 ha. The size of the ridged plots was 13.5 x 35 m and the size of the other plots 12 x 35 m. Crop rotation was biennial grass-clover followed by wheat (*Triticum aestivum* L.), intercrop (green manure), potato (*Solanum tuberosum* L.), intercrop (green manure), faba bean (*Vicia faba* L., variety "Divine") and barley (*Hordeum vulgare* L.). In 2007, faba bean was investigated on ridged and ploughed plots. Faba bean was sown on 4 April on ploughed (50 germinable seeds m^2) and on 14 April 2007 on ridged plots. The ridges with green manure were split off and the new ridges were formed and sown on the previous year's furrow position.

5.2.2 Soil sampling and bulk density

For estimating the bulk density, four soil plots of 50 x 50 cm on ploughed and 25 x 50 cm on ridged plots were cleared of vegetation on eight faba bean plots in April 2007. On the ploughed plots, four cylinders (100 cm^3) were taken at each depth from the soil surface, from 5 cm, 15 cm, 25 cm and 35 cm depth. On the ridged plots, the contour had to be taken into consideration (Fig. 18).

The soil samples were taken under the crown (5, 15, 25, 35 cm depth) and in the west furrow (5, 15, 25, 30 cm depth) from the soil surface. For the first depth at the crown, the top 5 cm of the soil were removed. Three cylinders according to the defined diameter of the ridge surface were placed west, middle and east on that surface with four replicates, respectively. For the 15 and 25 cm depth another 5 cm

of the soil was removed in each case, resulting in a larger surface because of the sinusoidal form of the ridge. According to the larger diameter of the ridge, four cylinders were taken with four replicates, respectively. Under the crown at 35 cm depth, just one row in the middle of the former ridge was sampled. In the furrows, soil samples were taken in line at each depth with four replicates. Wheel-tracked areas in the plots were excluded from sampling.

The soil sampling for estimating microbial biomass, mineral nitrogen and soil water content was carried out with a soil auger (1.5 cm diameter) under vegetation. In ridged plots, a raster according to the ridge contour was used (Fig. 19): On the evaluated ridge nine positions with intervals of 10 cm linear distance were marked, from west to east: furrow 1 (F1), furrow 2 (F2), shoulder 1 (S1), shoulder 2 (S2), crown (Cr), shoulder 3 (S3), shoulder 4 (S4), furrow 3 (F3), furrow 4 (F4). The original soil surface on ploughed plots was reference elevation (= 0.0 m) for the soil depths on the ridge. In ridged and ploughed plots soil samples were taken in 10 cm sections to a depth of 30 cm. At least ten subsamples were mixed to one soil sample. On the ridges, where the positions S2, Cr and S3 rose above the reference elevation, additional samples were taken in each case (Cr: 10-0 cm; S: 5-0 cm).

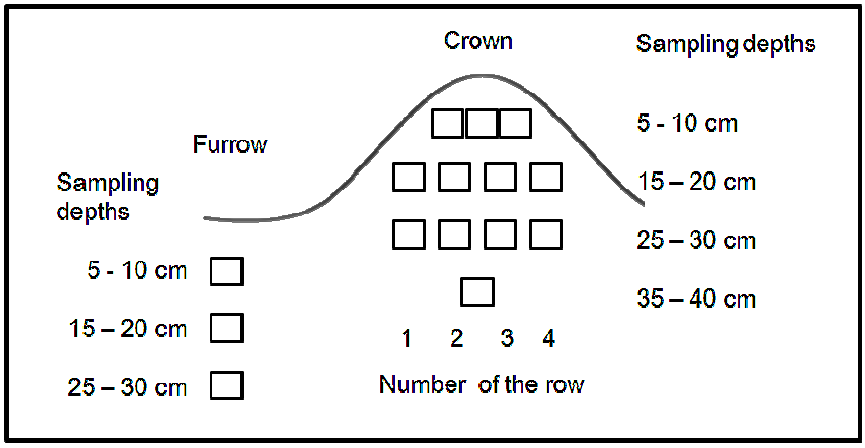


Figure 18: Sampling scheme for bulk density in ridges. Squares show position of the sampling cylinders.

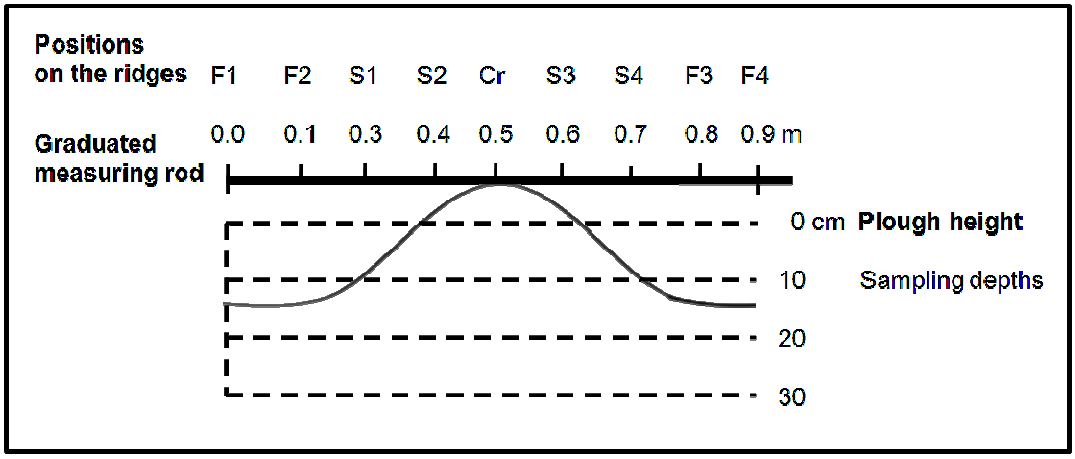


Figure 19: Ridge scheme with sampled positions and depths under faba bean *(Vicia faba* L.*)* in 2007.

5.2.3 Microbial biomass

Microbial biomass C and microbial biomass N were estimated by the chloroform-fumigation-extraction method (Brookes et al., 1985; Vance et al., 1987) using the pre-extraction procedure of Mueller et al. (1992) to exclude living roots from the samples. For pre-extraction, 30 g of moist soil was weighed in two polyethylene bottles, one for the fumigated and one for non-fumigated treatment. Then, the soil was shaken horizontally with 100 ml 0.05 M K_2SO_4 at 200 rev m^{-1} for 30 min. The soil suspension was transferred completely into beakers with a further 25 ml 0.05 M K_2SO_4. All visible roots, root fragments and foreign material were picked out and weighed. In a second step the suspension was stirred and transferred completely into filters with 25 ml 0.05 M K_2SO_4. For fumigation, the filters with the extracted soil were immediately fumigated for 24 h at 25°C with ethanol-free $CHCl_3$. The non-fumigated samples were left in the filters over night. The fumigated and non-fumigated soil in the filters was extracted again with 100 ml 0.5 M K_2SO_4 by horizontal shaking at 200 rev m^{-1} for 30 min. Organic C was measured with a Dima-TOC 100 automatic analyzer (Dimatec, Essen, Germany). The amount of the microbial biomass was calculated as E_C / k_{EC}, where E_C = (organic C extracted from fumigated soils) - (extracted organic C from non-fumigated soils) and k_{EC} = 0.45

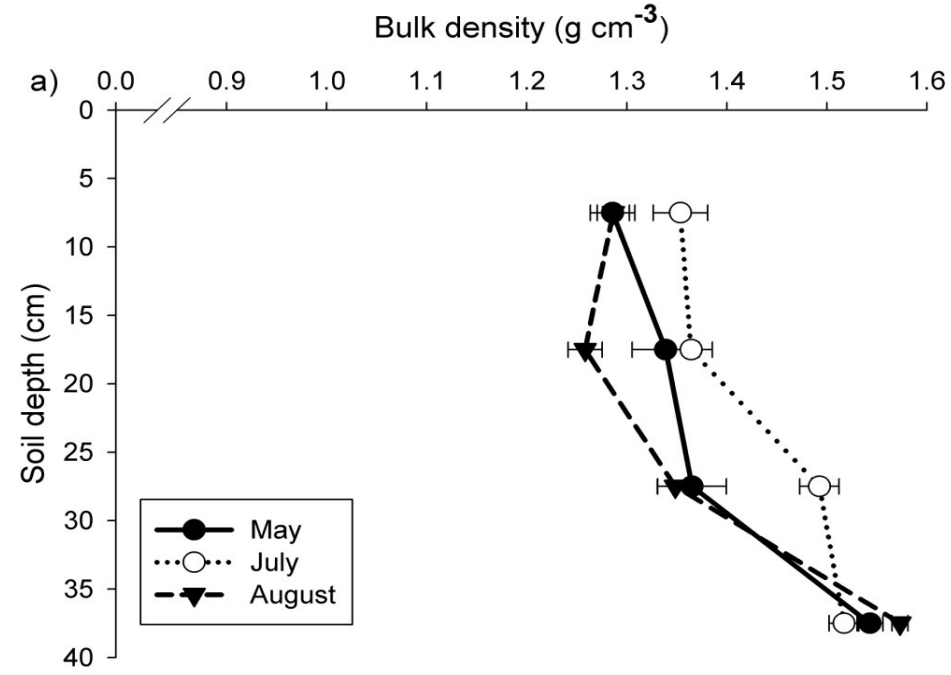
(Wu et al., 1990; Joergensen, 1996). The N of the microbial biomass was calculated as E_N / k_{EN}, where E_N = (extracted total N from fumigated soils) - (extracted total N from non-fumigated soils) and k_{EN} = 0.54 (Brookes et al., 1985; Joergensen and Mueller, 1996).

Inorganic nitrogen was the sum of nitrate (NO_3^-) and ammonium (NH_4^+) and determined in the pre-extracts and in the non-fumigated extracts of the chloroform-fumigation-extraction procedure. Ion concentrations were measured with a continuous flow analyzer (Evolution II auto analyzer, Alliance Instruments, Cergy - Pontoise, France). All results are based on oven-dried soil (105°C, approximately 24 h).

5.3 Results

5.3.1 Ploughed plots

Bulk density increased with soil depth (Fig. 20a). The values ranged from 1.3 g cm^{-3} at 10 cm depth to 1.6 g cm^{-3} at 35 cm depth. The inorganic N content ranged from 4.6 mg kg^{-1} soil at 20 cm depth in July to 11.1 mg kg^{-1} soil at 30 cm in May (Fig. 21a). Differences in concentrations between the three months were generally low. The soil water content ranged from 15% at 30 cm depth in July to 19% at 0-10 cm depth in May (Fig. 21b). At 10 cm and 30 cm depth, the contents of microbial biomass C (Fig. 22a) and microbial biomass N (Fig. 22b) remained roughly constant at 215 and 33 µg g^{-1} soil, respectively, throughout the experimental period. At 20 cm depth, the contents of microbial biomass C and microbial biomass N showed a significant 8% and 4% increase in July. Throughout the experimental period, the microbial biomass C, the microbial biomass N and the inorganic N contents were highly significantly correlated (data not shown). The microbial biomass C/N ratio varied in a small range around 6.4.



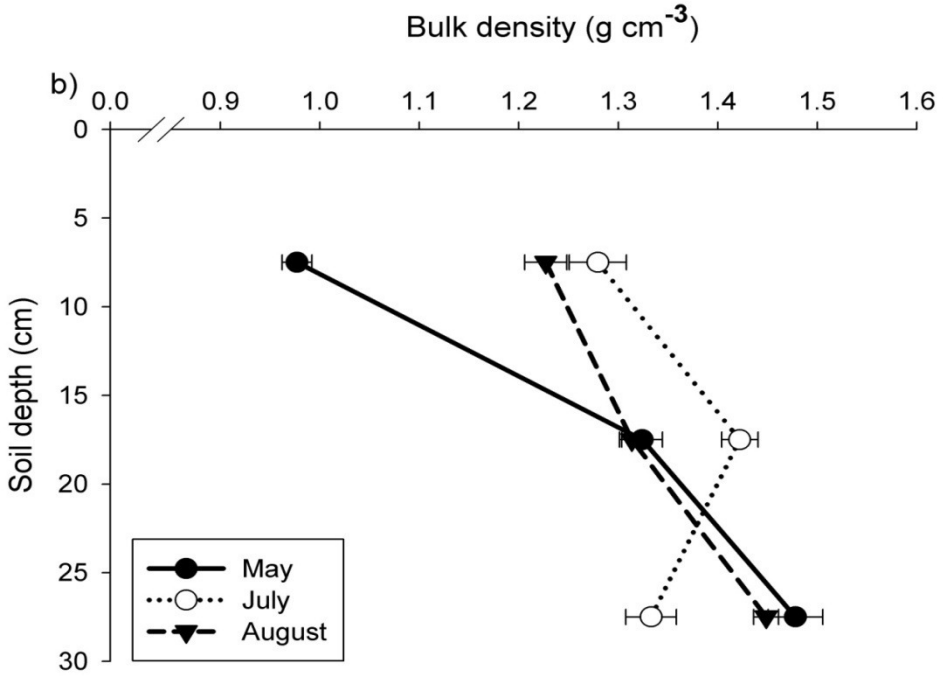


Figure 20a: Bulk density (g cm^{-3}) in ploughed plots under faba bean (*Vicia faba* L.) in 2007.

Figure 20b: Bulk densities (g cm^{-3}) in ridged plots under furrow in 2007.

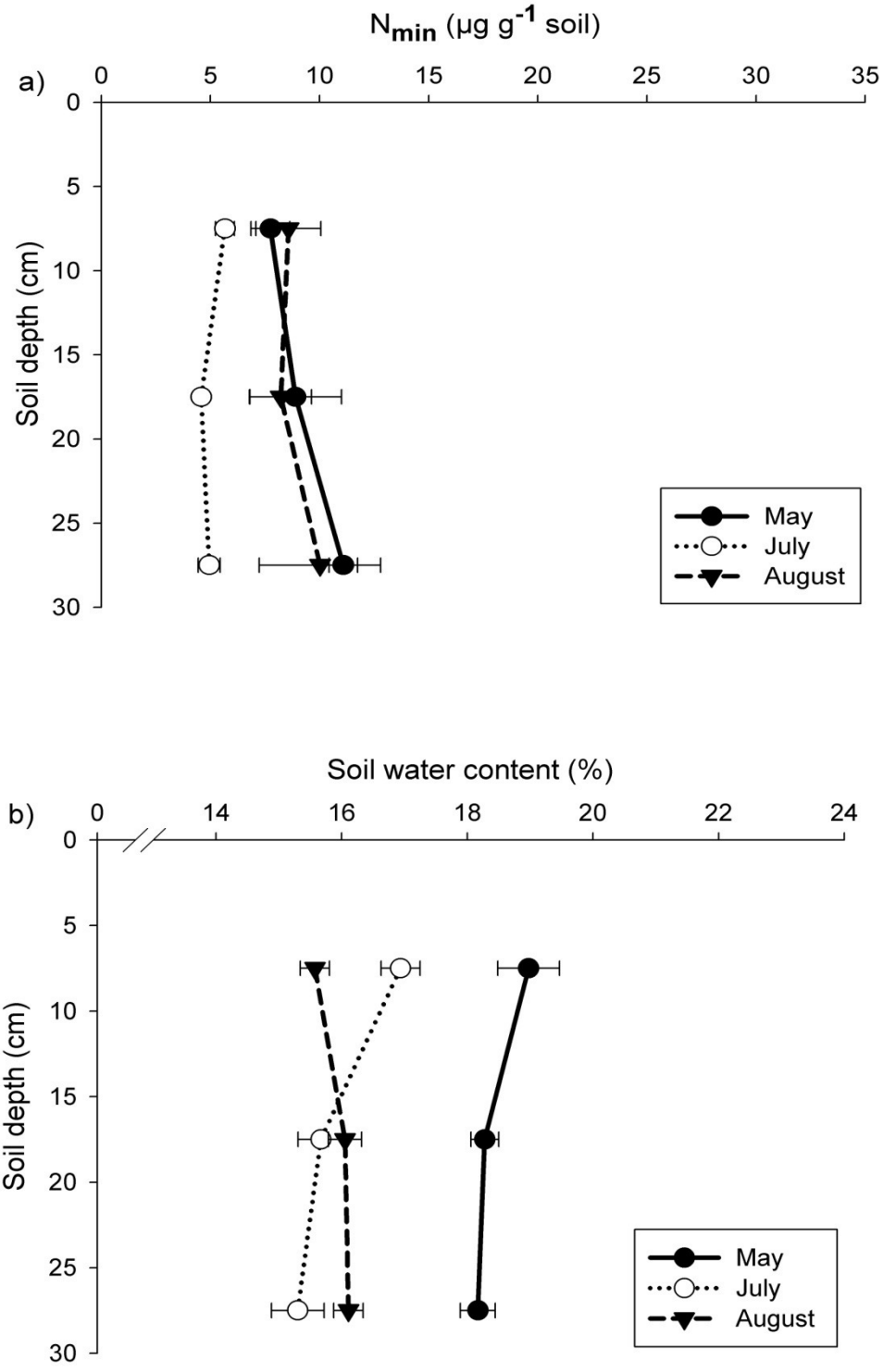


Figure 21a: Contents of inorganic nitrogen in ploughed plots under faba bean (*Vicia faba* L.) in 2007.

Figure 21b: Soil water contents in ploughed plots under faba bean (*Vicia faba* L.) in 2007.

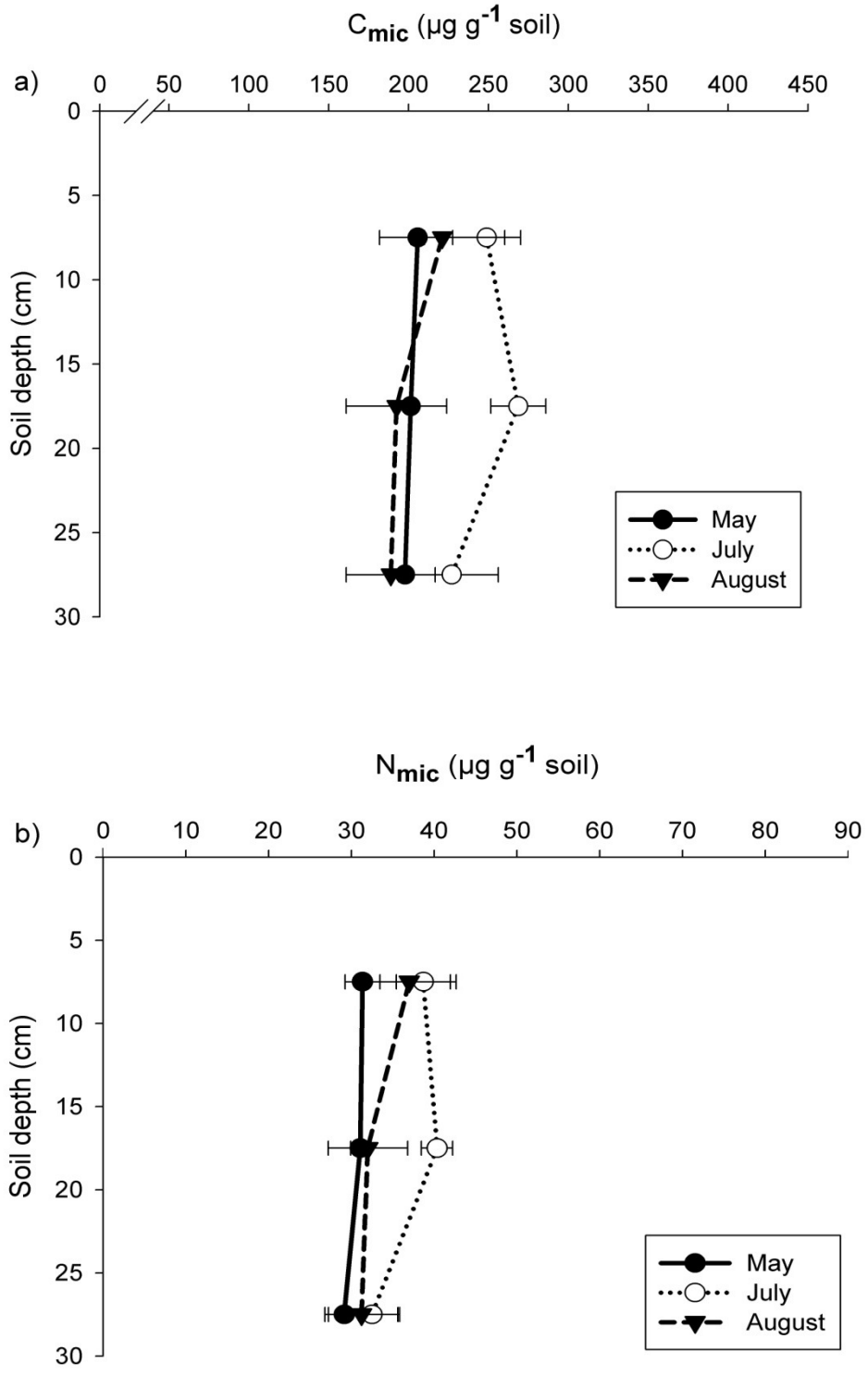


Figure 22a: Contents of soil microbial biomass carbon in ploughed plots under faba bean (*Vicia faba* L.) in 2007.

Figure 22b: Contents of soil microbial biomass nitrogen in ploughed plots under faba bean (*Vicia faba* L.) in 2007.

5.3.2 Ridged plots

In the furrows of the ridged plots (Fig. 20b), bulk density ranged from 1.0 at 10 cm depth to 1.5 g cm^{-3} at 30 cm depth, both values measured in May. Bulk density was highest at 10 and 20 cm depth in July and at 30 cm in May. Excluding the furrows, bulk density always increased down the profile from 1.0 g cm^{-3} to 1.4 g cm^{-3} at 35 cm depth (Fig. 23). In May, different areas of same bulk densities were found. The most pronounced area (1.0 g cm^{-3}) was at 12-18 cm depth with a well-defined ridge scheme. Bulk densities were lower in the outer rows than in the middle of the ridge (row 2 to 3). Below 25 cm depth, the areas with same bulk density formed linear bands. In July, the ridge was solidified down to 30 cm depth, the bands became larger and moved downwards. At 18 cm depth, the inner rows showed slightly higher bulk densities than the rows at the edges. In August, the ridge showed nearly the same pattern as in July.

At all three sampling dates, the inorganic N contents ranged from 3.1 mg kg^{-1} in furrow F1 in July to 27.8 mg kg^{-1} in the crown in May (Fig. 24a) and always decreased with depth. In May, a ridge scheme with highest inorganic N contents was observed in the crown. The first area of high inorganic N content was measured in furrow F1 and the second in the centre of the ridge with extensions into the upper parts of the crown and in the direction of furrow F4. In July, the inorganic N contents were on a lower level at all depths compared to those in May and August.

The soil water content decreased with time, i.e. highest percentages (17-20%) were observed in May, followed by July (14-20%) and August (15-18 %) (Fig. 24b). A decrease in soil water content was always found down to 10 to 30 cm depth followed by a slight increase. In May and July, the highest soil water contents were measured in shoulder S2. High water contents were also measured in furrows F1 and F4 at 0-30 depth. Lowest water contents were always found in shoulders S3 and S4. In July, drier areas were observed especially in shoulders S1 to S4 at 20-30 cm depth. In August, the soil water content did not vary much, i.e. the areas with the same soil water content were larger than in July. The soil water content showed a significant linear relationship with the inorganic N content throughout the

experimental period (Table 5). Both properties were negatively correlated with the bulk density.

Highest microbial biomass C contents of roughly 300 µg g^{-1} soil were always measured in the crowns in July, followed by August and May (Fig. 25a). The lowest contents of microbial biomass C were measured in May (85 µg g^{-1} soil) and July (137 µg g^{-1} soil) in furrow F1 and in August in furrow F4 (113 µg g^{-1} soil). At all sampling dates, the microbial biomass C contents at each position decreased with depth and any visible crown effect was lost with depth. Microbial biomass N was highly significantly correlated to the microbial biomass C (Table 5). Both microbial properties were also negatively correlated with the bulk density. The average C/N ratio of 6.5 ranged from 5.2 to 7.8 during the investigation period.

Table 5 Pearson correlation coefficients between the different soil parameters (** $p \leq 0.01$; 0-30 cm; n = 72) in the ridges (N_{mic}: soil microbial nitrogen, N_{min}: soil inorganic nitrogen, Bd: bulk density).

	N_{mic}	N_{min}	H_2O	Bd
Microbial biomass C	0.89**	0.46**	0.07	-0.47**
Microbial biomass N		0.49**	0.11	-0.51**
Mineral N			0.41**	-0.47**
Soil water content				-0.32**

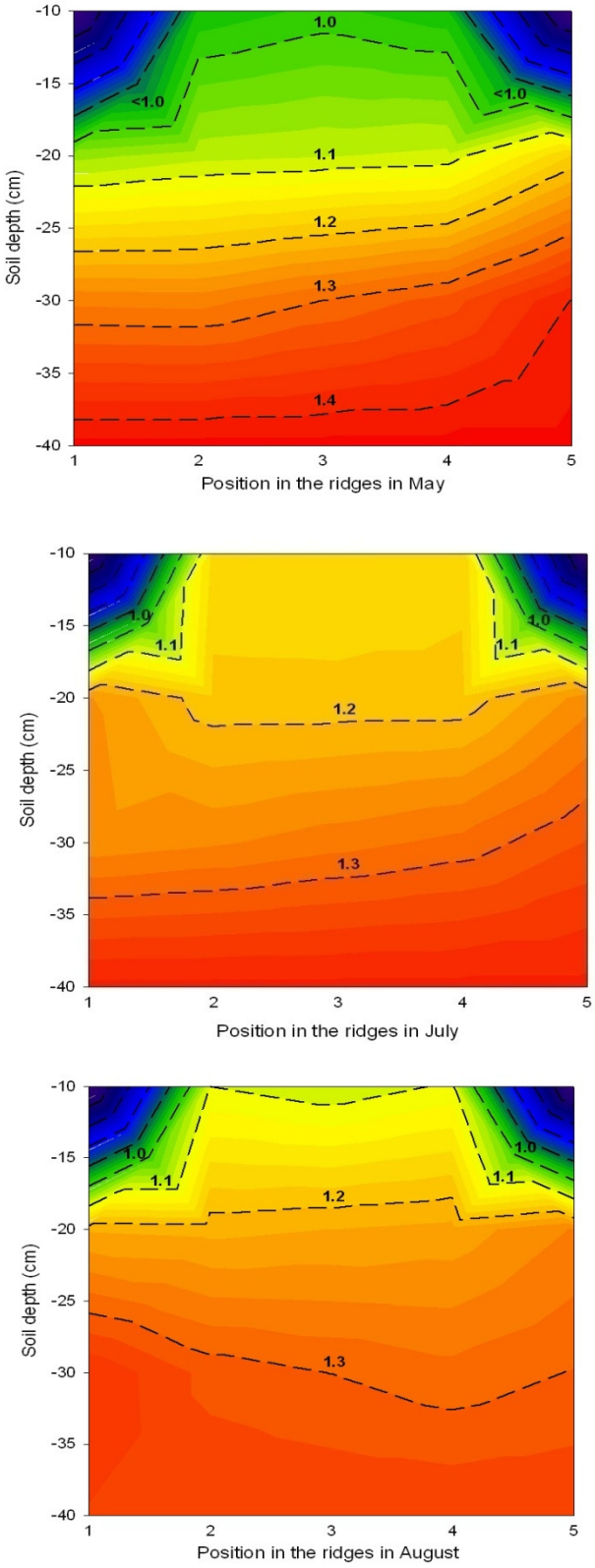


Figure 23: Bulk densities (g cm^{-3}) in ridged plots in 2007. Dashed lines separate areas of different bulk density.

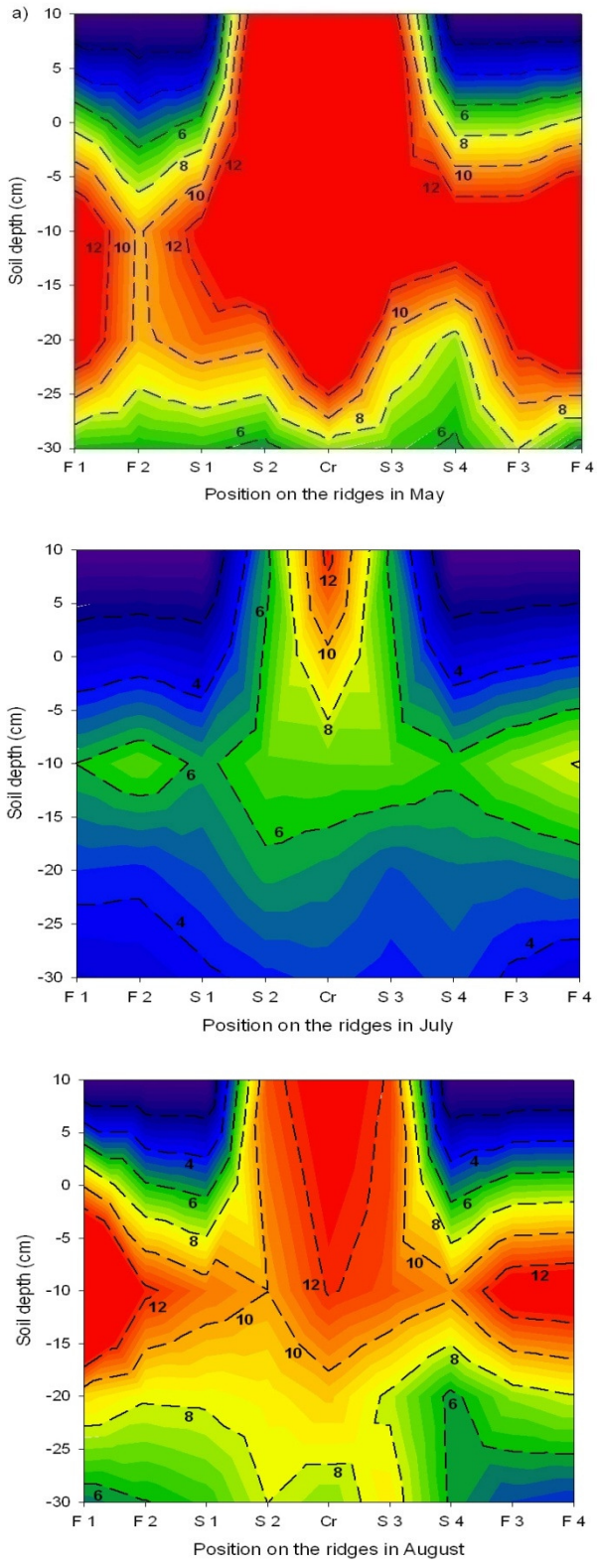


Figure 24a: Spatial distribution of inorganic nitrogen in ridged plots under faba bean in 2007 (F: Furrow; S: Shoulder; Cr: Crown). Dashed lines separate areas of different inorganic nitrogen contents.

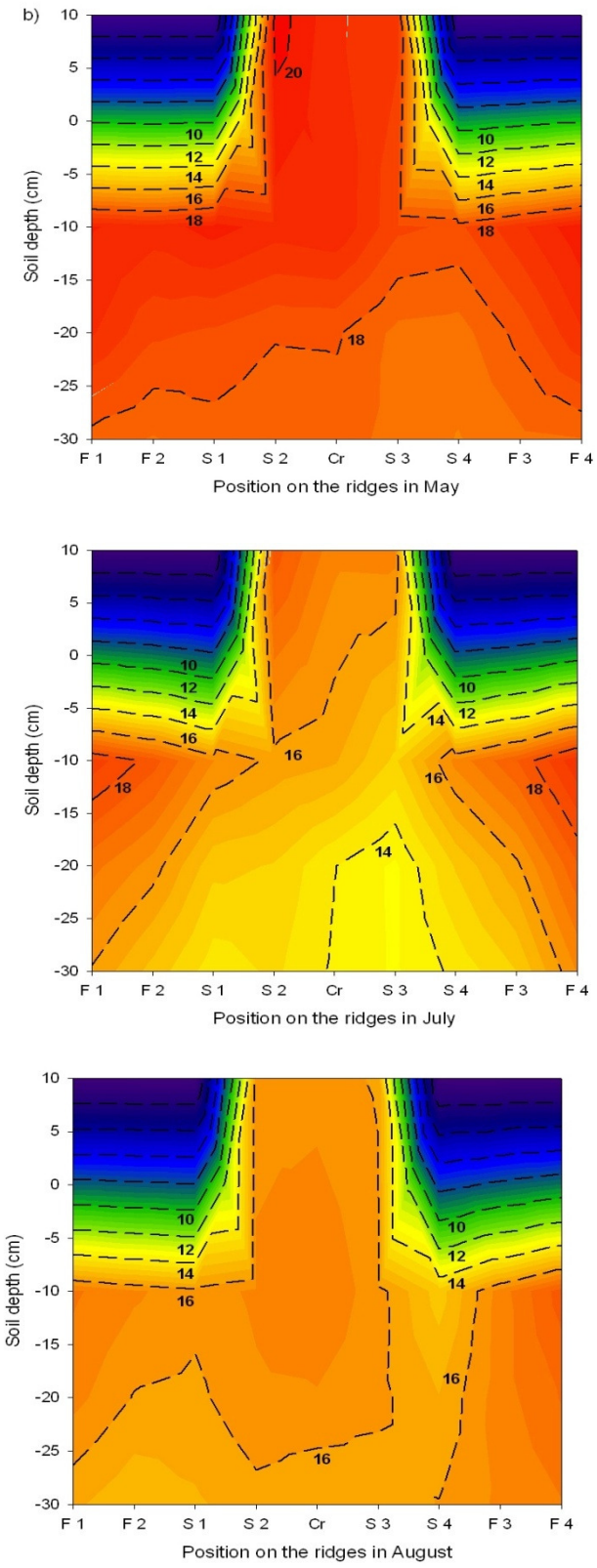


Figure 24b: Spatial distribution of soil water in ridged plots under faba bean in 2007 (F: Furrow; S: Shoulder; Cr: Crown). Dashed lines separate areas of different soil water contents.

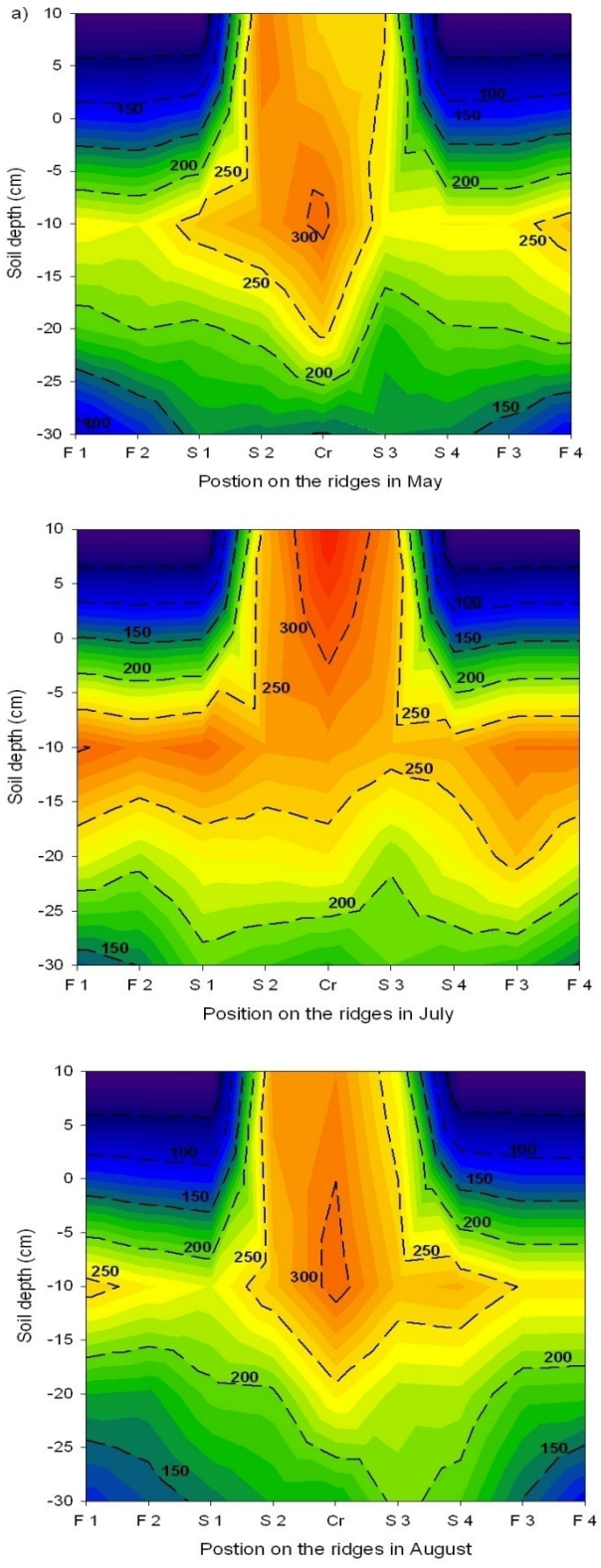


Figure 25a: Spatial distribution of soil microbial biomass carbon in ridged plots under faba bean in 2007 (F: Furrow; S: Shoulder; Cr: Crown). Dashed lines separate areas of different soil microbial biomass carbon concentrations.

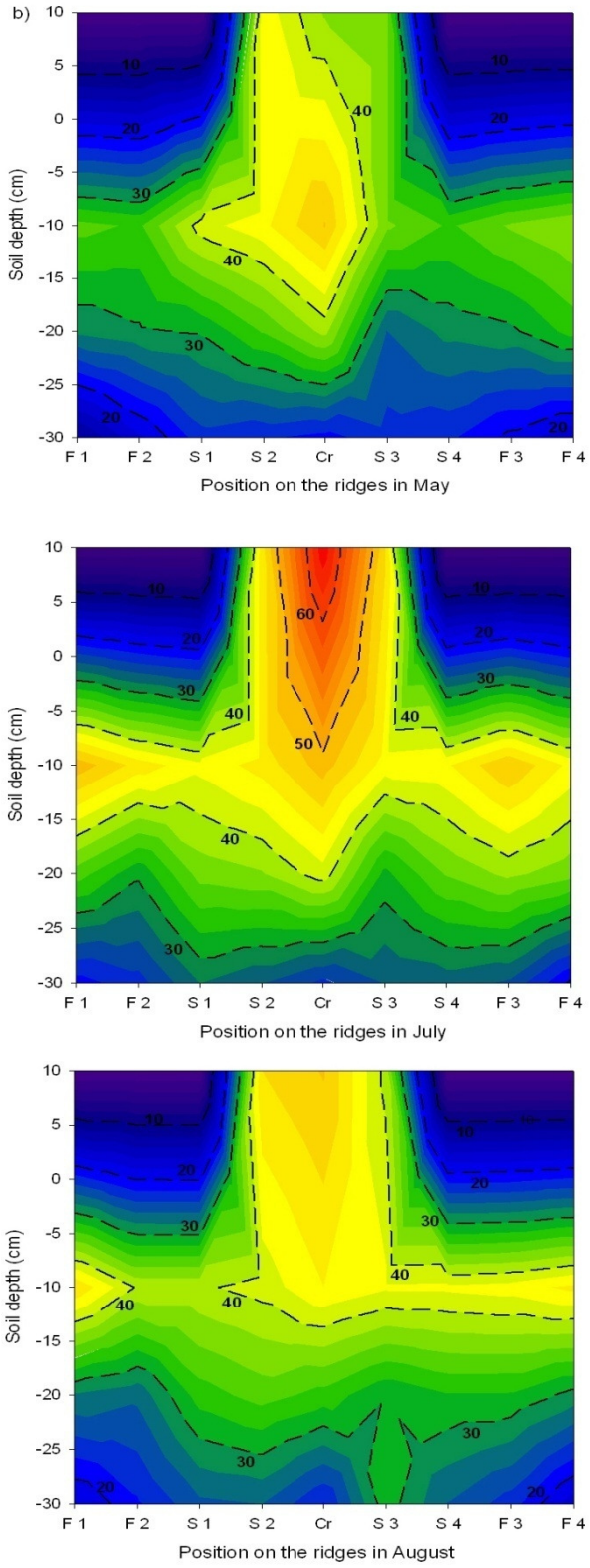


Figure 25b: Spatial distribution of soil microbial biomass nitrogen in ridged plots under faba bean in 2007 (F: Furrow; S: Shoulder; Cr: Crown). Dashed lines separate areas of different soil microbial biomass nitrogen contents.

5.4 Discussion

The mean microbial biomass C content of 220 µg g^{-1} soil observed throughout the experimental period in the different plots was in the lower part of the range observed in arable Luvisol sites in Central Europe (Anderson and Domsch, 1989; Röver and Kaiser, 1999; Dilly et al., 2003, 2004; Nieder et al., 2008). In 2003, the contents of microbial biomass C and microbial biomass N were homogeneously at 156 and 31 µg g^{-1} soil, respectively, at the experimental site (Brandt and Heß, 2004). The seasonal variations between the three sampling days, especially in the ploughed plots, were below 10%. This percentage is even lower than the results of Kaiser and Heinemeyer (1993) and Joergensen et al. (1994) for arable Luvisols of Northern Germany and it is also lower than the seasonal variations summarized by Wardle (1998) from data of arable sites all over the world. Also, the mean microbial biomass N content of 36 µg g^{-1} soil in the different plots was in the lower part of the range observed in arable Luvisol sites in Central Europe (Dilly et al., 2004; Nieder et al., 2008). The mean microbial biomass C/N ratio of 6.5 is close to the estimated mean of 6.7 set by Jenkinson (1988) for a common soil microbial community to calibrate the k_{EN} value (Joergensen and Mueller, 1996). Ridging apparently has no marked effects on microbial N storage in comparison to ploughing, suggesting similar microbial communities and the absence of strong nutrient limitations.

In the plough plots, microbial biomass C, microbial biomass N, and N mineralization did not reveal any marked depth gradient at 0-30 cm depth in accordance with Lavahun et al. (1996). This suggests homogeneous conditions for microbial life under plough tillage. In contrast, the ridged plots revealed strong spatial inhomogeneity, reflecting the different positions in furrows, shoulders and crown. This is a striking feature of the present results and might be caused by different effects of (1) bulk density, (2) water content, (3) plant residue distribution, and (4) root growth on microbial biomass and activity.

In both tillage systems, bulk density usually increased with soil depth, reaching a maximum of between 1.5 and 1.6 g cm^{-3} at 30-40 cm depth in the ploughing pan. This is in line with the results of others in arable Luvisols (Lavahun et al., 1996; Meyer et al., 1996; Etana et al., 1999; Olesen and Munkholm, 2007; D'Haene et al.,

2008). In the crown and the shoulders of the ridges, bulk density was roughly 0.2 to 0.1 g cm^{-3} lower than in the ploughed plots and the furrows of the ridged plots. This difference decreased with depth and during the cropping season, especially from July to August. A similar pattern was reported by Liebig et al. (1993) for ridges and furrows in the US Corn Belt. However, Stone and Heslop (1987) reported no significant differences between the bulk densities of ridges and a decrease in a mouldboard plough tillage system after 3 years. This was supported by Vinther and Dahlmann-Hansen (2005) for the soil at 5-10 cm depth. Katsvairo et al. (2002) found even lower bulk densities at 10-15 cm depth in mouldboard ploughed plots (1.2 g cm^{-3}) in comparison with the ridges (1.3 g cm^{-3}) at the six leaf stage of corn, this difference diminished later. Also, Pikul Jr. et al. (2001) reported a higher bulk density of the ridged (1.52 g cm^{-3}) in comparison with mouldboard ploughed soil (1.44 g cm^{-3}) at 0-20 cm depth. Although the bulk densities of the present experiment did not reach extremely high values at the different positions of the ridges, the bulk density caused negative effects on the microbial biomass as observed by Kaiser and Heinemeyer (1993), Nieder et al. (1995), and Ahl et al. (1998). For this reason, bulk density seems to be important for the observed spatial differentiation of microbial biomass C, microbial biomass N, and N mineralization in the ridged plots.

Although the microbial biomass C and N were not related to the soil water content, the microbial turnover was probably indirectly affected by the water content, as suggested by the positive correlation between soil moisture and inorganic N content. This was likely caused by the sinusoidal form of the ridges, which influences the distribution of precipitation and with this the soil water regime. Bargar et al. (1999) observed higher infiltration rates in furrows than in crowns, following a lateral soil water movement into the ridge body. This phenomenon was explained by a negative hydraulic gradient of the drier areas in the ridge crown (Benjamin et al., 1990; Waddell and Weil, 2006). Jaynes and Swan (1999) found lower tracer concentrations in the furrows than under the ridge crown and shoulders, indicating higher infiltration rates. Henriksen et al. (2006) assumed that precipitation ran down the shoulders and infiltrated primarily in the furrows, thereby protecting inorganic N of the ridge crown from leaching. Even when the

soil was puddled as observed during the present field trial, precipitation had more time to infiltrate in the furrows compared to the shoulders. Some high soil water contents were visible in the crowns, which might be caused by the rougher surface on the crown (Taconet and Ciarletti, 2007). An additional reason is probably the stem-flow down to the base of faba beans, where infiltration was facilitated in comparison with the puddled soil surface nearby. In the present ridge tillage system of Turiel, the crowns of the ridges were newly formed every year on the previous year's furrows, always cutting off the pore system connecting subsoil with upper soil. So, capillary water supply for the plants from the deeper soil layer was reduced in comparison with permanent ridges as described by Borin and Sartori (1995) in the American Corn Belt.

The hot spots of microbial biomass were located in the central body of the ridges (May and August) and in the crown (July). Plant residues were mainly incorporated into the central body during ridge formation. In addition, this area contained high water contents and it was the preferred place for root growth. During crop development, roots transfer large amounts of C and N as rhizodeposition into the soil (Nguyen, 2003; Wichern et al., 2007, 2008), especially in the vegetative period from May to July (Keith et al., 1986; Nieder et al. 1995; Kuzyakov and Domanski, 2000; Fu et al., 2002). Faba beans released up to 78% of the total below-ground plant biomass N as rhizodeposition (Mayer et al., 2003). During maturation, an increasing amount of dead roots serve as substrate for soil microorganisms, resulting in increased microbial biomass contents.

5.5 Conclusions

In contrast to ploughing, the ridge tillage system of Turiel led to strong spatial variability in bulk density, soil water content, inorganic nitrogen and microbial biomass C and microbial biomass N under faba bean. This variability is mainly due to differences in bulk density, which has an impact on soil moisture, residue distribution and root growth. The ridges were formed every year with a tillage depth of 30 to 35 cm. For this reason, the Turiel tillage system cannot be regarded as a

reduced system, although its intensity is lower than that of the conventional ploughing system.

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6 Pflanzenbauliche Parameter

6.1 Erträge von 2006 bis 2008

Die Ernte der Parzellen erfolgte mit einem Parzellenmähdrescher. Das Erntegut wurde anschließend gereinigt und gewogen. Die Mittelwerte (Tab. 6) ergeben sich aus den Erntemengen je Block des Versuches (n = 4). Allein bei den Erträgen von Ackerbohne 2007 und Sommerweizen 2007 lassen sich signifikante Unterschiede zwischen dem Dammkultur-System sowie Pflug und Ecomat nachweisen (Tab. 6). Der ungewöhnlich hohe Mäusebefall im Jahr 2007 führte dazu, dass die Sommerweizenparzellen nicht mit dem Mähdrescher beerntbar waren. Aus diesem Grund wurden die Sommerweizenerträge errechnet. Hierzu wurden in den Pflug- und Ecomat- Parzellen die Stoppeln auf 1 m Länge innerhalb einer Drillreihe, mit 12-facher Wiederholung, gezählt. In den Dammkulturparzellen wurden die Stoppeln mit Hilfe eines Rahmens (Fläche = 0,9 m²) in vierfacher Wiederholung ausgezählt. Um das Gewicht je Ähre zu ermitteln, wurden 150 Ähren in 6-7 Wiederholungen je Parzelle geschnitten und ausgewogen (g $Ähre^{-1}$). Dieser Wert wurde anschließend mit der Anzahl der Stoppeln je m² multipliziert und auf Tonnen pro Hektar (t ha^{-1}) hochgerechnet.

Verglichen mit den Erträgen aus Sortenversuchen des Landesbetriebes Landwirtschaft Hessen (LLH) für die Wintergerste (2006; Sorte: Mercedes; 4,7 t ha^{-1}) (Völkel, 2006), liegen die Erträge des Bodenbearbeitungsversuches (besonders die der Dammkultur) deutlich niedriger (Tabelle 6). Im Jahr 2008 wiederholt sich diese Tendenz, wobei die Differenz zu den vom LLH angegebenen Ertrag größer wurde (Durchschnittsertrag aus 15 Sorten: 5,7 t ha^{-1}) (Witzel et al., 2008). Die Erträge für ökologisch erzeugten Sommerweizen des LLH lagen 2007 bei 4,2 t ha^{-1} (Durchschnittsertrag aus 10 Sorten) (Völkel, 2007a). Diese Zahlen wurden vom Dammkultur-System nicht erreicht, jedoch vom Pflug und Ecomat deutlich übertroffen. Diese potenzielle Überschätzung hängt höchstwahrscheinlich mit der Berechnung der Erträge auf dem Bodenbearbeitungsversuch in dem Jahr zusammen. Die geringe Erntemenge auf den Dämmen ist auf einen geringeren

Kornertrag je Ähre (Pflug: 1,3 g Ähre^{-1}; Dammkultur: 1,1 g Ähre^{-1}; Ecomat: 1,3 g Ähre^{-1}) zurückzuführen.

Die Erträge der Ackerbohne (2007; Sorte Divine) auf dem Bodenbearbeitungsversuch waren insgesamt sehr gering im Vergleich zu den Erträgen des LLH (2,48 t ha^{-1}) (Völkel, 2007b). Hierbei fällt der besonders geringe Ertrag auf den Dammkulturparzellen auf. Insgesamt war das Jahr 2007 von starker Trockenheit und einem sehr hohen Mäusebefall auf dem Versuch geprägt. Dies trug in hohem Maße zu den schlechten Erträgen in dem Jahr bei. Der Bruttoertrag der ökologisch erzeugten Kartoffeln 2008 in Hessen lag im Durchschnitt bei 34,0 t ha^{-1} (persönl. Gespr., Völkel, 2009). Damit können die Erträge, die auf dem Bodenbearbeitungsversuch erzielt wurden, als gering (Dammkultur) bis mittel (Pflug, Ecomat) eingestuft werden.

Tabelle 6 Gereinigte Ernteerträge des Bodenbearbeitungsversuches zwischen 2006 und 2008. Unterschiedliche Buchstaben in den Spalten zeigen signifikante Unterschiede zwischen den Mittelwerten der Bodenbearbeitungssysteme (Tukey/Kramer, $p < 0,05$; $n = 4$). Zahlen in Klammern zeigen den Standardfehler des Mittelwertes ($n = 4$).

	Winter-gerste 2006	Ackerbohne 2007	Sommer-weizen 2007*	Winter-gerste 2008	Kartoffeln 2008
	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})	(t ha^{-1})
Pflug	4,28 a	1,57 a	7,77 a	5,01 a	33,70 a
	(± 0,3)	(± 0,1)	(± 0,8)	(± 0,2)	(± 0,9)
Dammkultur	3,64 a	0,69 b	3,31 b	4,22 a	28,55 a
	(± 0,3)	(± 0)	(± 0,3)	(± 0,2)	(± 1,8)
Ecomat	4,38 a	1,49 a	7,84 a	5,06 a	30,75 a
	(± 0,2)	(± 0,1)	(± 0,5)	(± 0,2)	(± 1,9)

(*errechnete Werte, Mähdrusch war nicht möglich)

Bezogen auf alle dargestellten Jahre und Fruchtarten, wurden auf den Dammkulturparzellen mit Abstand die geringsten Erträge erzielt, gefolgt von Ecomat und Pflug.

Diese Reihenfolge, bezogen auf die Erträge aus den ersten beiden Versuchsjahren wird ebenfalls von Quintern (2006) beschrieben. Vergleicht man die Erträge einer Fruchtart über alle Bodenbearbeitungssysteme hinweg, liegen die Erträge bei Quintern (2006) im Durchschnitt für die Wintergerste 21% und für Kartoffeln 12% unterhalb der Erträge von 2006-2008. Dies steht im starken Wiederspruch zu den von ihm angegebenen Erträgen für Ackerbohne. Deren Werte 59% über denen des Jahres 2007 liegen. Besonders im Dammkultur-System fällt ein Sinken der Erträge um 75% (von 2,75 t ha^{-1}) auf. Die Erträge des Pflug-Systems sinken um 50% und die des Ecomat-Systems um 52% im Jahr 2003/2004 verglichen mit dem Jahr 2007. Diese große Differenz kann nicht auf den Mäuseschaden im Jahr 2007 zurückzuführen sein.

Stellt man außerdem die Erträge der Dammkultur (2006-2008) mit den Erträgen aus konventionellen Sortenversuchen für Wintergerste 2006, 2008 (7,75 t ha^{-1}; 7,69 t ha^{-1}) (Witzel, 2006; Witzel und Bock, 2008) und Ackerbohne 2007 (2,46 t ha^{-1}) (Witzel, 2007) gegenüber, ist festzustellen, dass diese für die Wintergerste um 48% und bei der Ackerbohne sogar um 72% niedriger liegen. Das Dammkultur-System auf dem Bodenbearbeitungsversuch erzielt somit keine höheren Erträge im Vergleich zum Flachanbau mit Ecomat und Pflug. Darüber hinaus, sind die gezeigten Erträge im Vergleich zum konventionellen Landbau so gering, dass sie nicht konkurrenzfähig sind und damit keine Alternative bieten.

Bezieht man zusätzlich die erzielten Erträge auf die CO_2 Freisetzung während der Wachstumsperiode je Hektar und Tag ist festzustellen, dass bei der Erzeugung einer Tonne Ackerbohnen 0,038 t CO_2 von den gehäufelten und nur 0,018 t CO_2 von den gepflügten Parzellen entweichen.

6.2 Inhaltsstoffe im Erntegut 2006-2008

Zur Ermittlung einiger Inhaltsstoffe, wurde das gereinigte Erntegut in zwei Mahlschritten auf 1 mm Größe gemahlen. Untersucht wurden Wintergerste (2006, 2008), Sommerweizen (2007) und Ackerbohne (2007). Die Analysen wurden mit Hilfe der Nahinfrarotspektroskopie (NIRS) (Modell: S 6500; FOSS NIRSystem Inc.; Rellingen, Deutschland) durchgeführt. Hierbei werden durch die Infrarotstrahlung Moleküle angeregt. Die entstandene Schwingung wird vom Detektor aufgenommen und an einer bereits vorhandenen Eichreihe statistisch ausgewertet, wodurch auf die Konzentration im Erntegut geschlossen wird. Die NIRS-Methode wurde gewählt, um das Erntegut hinsichtlich der Parameter: Rohprotein, Rohfett, Rohfaser, Stärke sowie Gesamtzucker schnell und aussagekräftig zu untersuchen. Die Parameter sind Bestandteil der Analyse von Futtermitteln und ermöglichen eine erste Beurteilung der Inhaltsstoffe. Die Messwerte (bezogen auf Trockenmasse) sollen einen möglichen Einfluss der eingesetzten Bodenbearbeitungssysteme auf die Qualität des Erntegutes zeigen.

Die Messwerte (Tab. 7) zeigen keinen einheitlichen Einfluss eines Bodenbearbeitungssystems auf die Inhaltsstoffe. Auffällig ist jedoch, dass sich die Systeme Pflug und Ecomat ähnlich verhalten. Dies lässt auf vergleichbare Wachstumsbedingungen für Pflanzen schließen. Die Inhaltsstoffe der Gerste im Dammkultur-System hingegen sind häufig signifikant unterschiedlich zum Pflug- und Ecomat-System, wobei keine einheitliche Tendenz sichtbar ist. Quantitativ betrachtet, sind diese Unterschiede jedoch sehr gering und somit wirtschaftlich nicht bedeutsam. Die Ähnlichkeiten der Inhaltsstoffkonzentrationen im Pflug- und Ecomat-System sowie deren Unterschiede zum Dammkultur-System lassen sich hauptsächlich mit der unterschiedlichen Art und Weise der Einarbeitung von Ernteresten erklären. Beim Pflügen (und Ecomat) wird eine gleichmäßige Einarbeitung und Verteilung der Erntereste in den Boden erreicht. Dies resultiert in gleichmäßigeren Nährstoffbedingungen für die Pflanzen. In der Dammkultur hingegen werden Erntereste ungleichmäßig in Furche und Damm eingearbeitet. Dies führt zu räumlichen Unterschieden von Lagerungsdichte, mikrobieller Biomasse, Wassergehalt und anorganischen Stickstoff und damit zu

ungleichmäßigeren Bedingungen für das Pflanzenwachstum. Gleicht man die vorliegenden Messwerte (Mittelwert aller Bodenbearbeitungssysteme) mit der DLG Futterwerttabelle für Wiederkäuer (1997) (Tab. 8) ab, ist zu sagen, dass die Inhaltsstoffe der untersuchten Fruchtarten die vorgegebenen Werte einerseits über-, andererseits unterschreiten. Einzig im Parameter Stärke liegen die Ergebnisse des Bodenbearbeitungsversuches in jeder Fruchtart unterhalb der in der Futterwerttabelle angegebenen. Um einen weiterführenden Vergleich der Dammkultur hinsichtlich Inhaltsstoffe des Erntegutes mit anderen Bodenbearbeitungssystemen durchführen zu können, fehlen entsprechende Vergleichswerte.

Tabelle 7 Inhaltsstoffe des Erntegutes vom Bodenbearbeitungsversuch (2006-2008). Die Messung erfolgte mit der Nahinfrarotspektroskopie (NIRS). Unterschiedliche Buchstaben in den Spalten zeigen signifikante Unterschiede zwischen den Mittelwerten der Bodenbearbeitungssysteme (Tukey/Kramer, $p < 0,05$; $n = 4$). (Dammk. = Dammkultur).

		Roh-protein (% TM)	Roh-fett (% TM)	Roh-faser (% TM)	Stärke (% TM)	Gesamt-zucker (% TM)
Winter-	Pflug	9,26 b	4,31 b	5,15 a	58,29 a	3,77 b
gerste	Dammk.	10,55 a	4,62 a	5,20 a	56,22 b	4,04 a
2006	Ecomat	8,56 b	4,06 b	5,14 a	58,34 a	3,57 b
Acker-	Pflug	32,39 a	2,74 a	12,27 a	28,83 a	3,56 a
bohne	Dammk.	32,33 a	2,69 a	12,56 a	27,22 a	3,47 a
2007	Ecomat	32,51 a	2,68 a	12,19 a	39,49 a	5,58 a
Sommer-	Pflug	12,36 b	3,60 a	3,86 a	64,37 a	3,54 a
weizen	Dammk.	13,66 a	4,12 a	3,86 a	63,77 a	3,94 a
2007	Ecomat	12,65 b	3,67 a	3,77 a	64,77 a	3,61 a
Winter-	Pflug	10,55 a	3,29 a	4,78 a	56,71 a	3,26 a
gerste	Dammk.	10,58 a	3,01 b	4,84 a	55,33 b	3,00 b
2008	Ecomat	10,51 a	3,35 a	4,68 a	56,68 ab	3,27 a

Tabelle 8 Auszug aus der DLG Futterwerttabelle für Wiederkäuer (1997). Fett gedruckte Zahlen zeigen höhere (und gleiche) Werte der Futterwerttabelle im Vergleich zu den Messergebnissen des Bodenbearbeitungsversuches (Tabelle 7). Kursiv gedruckte Werte entsprechend niedrigere.

	Roh-protein (% TM)	Roh-fett (% TM)	Roh-faser (% TM)	Stärke (% TM)	Gesamt-zucker (% TM)
Wintergerste (Körner)	**12,4**	*2,7*	**5,7**	**59,9**	*1,8*
Ackerbohne (Samen)	*29,8*	*1,6*	*8,9*	**42,2**	**4,1**
Sommerweizen (Körner)	**15,8**	*2,4*	*2,5*	**65,3**	keine Angaben

7 Summary

Modern agriculture provides different tillage systems which have different demands. Generally, they can be divided in conventional tillage systems using the plough, reduced tillage systems and no-till systems. All tillage systems have specific impacts on the soil biological and soil physical properties as well as related processes. As there is still hardly any data on reduced tillage systems in organic agriculture, a field trial was established at the Hessian State Domain, where three tillage systems are compared. The tillage systems were a conventional ploughing system and reduced tillage systems, namely the ridge till system of Turiel and the Ecomat system by Kverneland. The ridge tillage system is characterized by a sinusoidal shaped soil surface. This special exposition might influence the spatial distribution of microbial biomass, microbial activity and related processes. Many studies have investigated ridge tillage systems with permanent ridges under conventional management, especially in the American Corn Belt. In contrast, a ridge tillage system with annual ridges, managed according to the principles of organic agriculture like the Turiel system, has not been investigated in detail yet. Therefore, almost only non-scientific descriptions and data on this management system are found. Therefore, this study was initiated to compare the ridge tillage system of Turiel with the conventional ploughing system focusing on: (1) soil physical and soil biological properties and their spatial distribution in ploughed and ridged soil; (2) the estimation of the CO_2 evolution. Moreover three *in situ* CO_2 measuring methods were evaluated for their usefulness under field conditions. (3) the transferability of investigated properties of the ridge tillage system using permanent ridges on the ridge tillage system of Turiel using annual ridges. Finally, a comparison of yields and some grain constituents of the plough, the ridge tillage and the Ecomat system was done to give further information on the tillage systems.

For investigating soil physical and soil biological parameters, soil samples were taken in the ploughed and ridged plots. Soil bulk density was determined at 5, 15 and 25 cm in the ploughed plots. In the ridges, the samples were taken under the crown and the west furrow (5, 15, 25, 35/30 cm) from below the soil surface. The soil sampling for estimating microbial biomass, mineral nitrogen and soil water

content was carried out using a soil auger in 10 cm sections down to 30 cm under vegetation. On the ridges, the sinusoidal form had to be taken into consideration. Therefore, nine positions were marked on the evaluated ridges with a linear distance of 10 cm respectively where the samples were taken. As a reference elevation the soil surface of the ploughed plots was used. The soil CO_2 evolution for determining the microbial activity was measured with a portable infrared gas analyzer (CIRAS) on bare and vegetated soil. Measurements took place on ploughed plots and on five positions on the ridges. For calculating the cumulated CO_2 evolution during the investigation period, the convex form of the ridges resulting in 878 m² (without vegetation) and 434 m² (with vegetation) larger soil surface per hectare in comparison with ploughed plots had to be considered.

The measurement for evaluating three different in situ CO_2 measuring methods took place at the Reinshof, the experimental farm of the University of Göttingen. A static chamber method, a static chamber method with an installed fan module (dynamic chamber) and the CIRAS (dynamic chamber) were compared. The static chambers consisted of PVC pipes with an end cap and were installed in the soil. The gas samples were taken with gas mice and analyzed in the laboratory with a gas chromatograph (GC). With the CIRAS the CO_2 concentration was measured directly in the field.

To evaluate the yields of the three tillage systems plough, ridge tillage and Ecomat at the Hessian State Domain, the yields of winter barley (2006 and 2008), summer wheat (2007), faba bean (2007) and potato (2008) were estimated and compared. The grain constituents roar protein, roar fat, roar fibre, starch and total sugar were measured with a near-infrared spectrometer for winter barley (2006, 2008), summer wheat (2007) and faba bean (2007). The measured values were compared with the look-up tables for feedstuff (ruminants) provided by the DLG (Deutsche Landwirtschafts-Gesellschaft).

Bulk density in the ploughed (1.3-1.6 g cm^{-3}) and the ridged plots (crown: 1.0-1.4 g cm^{-3}) increased with soil depth to a maximum of between 1.5 and 1.6 g cm^{-3}. Generally, the bulk density in the crown and shoulders (of the ridges) was 0.2 to 0.1 g cm^{-3} lower compared to the furrow and the ploughed plots. The differences decreased with depth and during the cropping season. On ploughed plots, the

microbial biomass C and microbial biomass N remained at 215 and 33 µg g^{-1} soil (10-30 cm) without a depth gradient. The microbial biomass C/N ratio varied around 6.4. The content of inorganic nitrogen ranged from 4.6 mg kg^{-1} soil (July, 20 cm depth) to 11.1 mg kg^{-1} soil (May, 30 cm depth). The soil water content was between 15% (July, 30 cm depth) and 19% (May, 0-10 cm depth). In the ridges, the microbial biomass C, the microbial biomass N, the inorganic N and the soil water content showed spatial heterogeneity. Highest contents of microbial biomass C (July, 300 µg g^{-1} soil) were observed in the crowns, lowest (May, 85 µg g^{-1} soil) in the furrows. The microbial biomass N was highly significantly correlated with the microbial biomass C. The average C/N ratio was 6.5 during investigation period. The content of inorganic N ranged from 3.1 mg kg^{-1} (July) in the furrow to 27.8 mg kg^{-1} (May) in the crown. The inorganic N content showed a significant linear relationship with the soil water content throughout the investigation period.

During the investigation period of 57 days, the ploughed plots evolved 9% (0.11 t CO_2-C ha^{-1}) more CO_2 compared to the ridged plots. But, the number of management operations was higher in the ridged plots (plough: 4; ridge tillage: 6), which causes additional CO_2 evolution. Due to the spatial heterogeneity of the bulk density, the soil water content and the microbial biomass in the ridges, the CO_2 evolution measured at different positions on the ridges showed also differences. Soil mean soil temperature (5 cm depth) was 0.1°C higher in the ridges compared to the ploughed plots.

The mean CO_2 evolution rate measured by the three different *in situ* methods increased significantly in the order static chamber < dynamic chamber < CIRAS by 40%. Compared to both other systems, the results showed most reliable data for the CIRAS, due to its independence on soil and air temperature. Furthermore, the CIRAS provides simple handling in the field and short measuring intervals. For the static and the dynamic chamber, the gas sampling in the field is time consuming and the analyzing in the laboratory with a gas chromatograph requires further efforts.

The ridge tillage system had 23% (2.4 t) lower and the Ecomat system 3% (0.6 t) lower yields in average of all crops and all years compared to the ploughing system (10.5 t). The yields combined with the CO_2 evolution per ha and day showed an amount of 0.018 t CO_2 day^{-1}, evolved for getting 1t of faba bean grains on ploughed

plots. In contrast 0.038 t CO_2 day^{-1} were evolved on 1 ha ridged plots for gaining 1t faba bean grains.

Significant differences in grain constituents between the different tillage systems were found for roar protein (winter barley 2006; summer wheat 2007), roar fat (winter barley 2006, 2008), starch (winter barley 2006, 2008) and sugar (winter barley 2006, 2008). The constituents of grains from the ploughing and the Ecomat system did resemble. They were often different to the measured values of the ridge tillage system. The tillage systems did not show a homogeneous impact on the quantity of the constituents for all crops. Compared to the look-up tables, the measured values did exceed (roar protein: barley, wheat; roar fibre: barley; starch: barley, faba bean, wheat; sugar: faba bean) and were below (the others) given quantities. No uniform trend was visible, except for starch in all crops, which for all tillage systems was consistent below the quantities given in the look-up table.

Consequently, for the comparison of the ridge tillage system of Turiel and the mouldboard ploughing system it can be concluded:

- In contrast to the ploughing system, the ridge tillage system led to high spatial variability in bulk density, soil water content, inorganic N, microbial biomass C and microbial biomass N, which however did not result in higher yields or better grain constituents.
- The mean soil temperature was 0.1°C higher in the ridges.
- The CO_2 evolution per ton yield was 53% higher in ridged plots compared to ploughed plots.
- The yields in the ridge tillage system of Turiel were markedly below the ones of the ploughed plots.
- The content of grain constituents in the ridge tillage system of Turiel were below the ones of the ploughing system.
- According to Metzke et al. (2007) the number of earthworms was significantly reduced in the ridge tillage system of Turiel compared to the mouldboard ploughing system.

Consequently, the positive parameters of the permanent ridge tillage systems are not transferrable to the annual ridge tillage system of Turiel. Furthermore, the ridge tillage system of Turiel is not an adequate alternative to the mouldboard ploughing system in organic agriculture.

8 Zusammenfassung

Die heutige Agrartechnik stellt vielfältige Bodenbearbeitungssysteme für verschiedenste Ansprüche bereit. Grundsätzlich lassen sie sich in das konventionelle Pflug-System, reduzierte Systeme und Direktsaat unterteilen. Alle Bodenbearbeitungssysteme üben spezifische Einflüsse auf bodenbiologische und bodenphysikalische Eigenschaften und die damit verbundenen Prozesse aus. Da besonders im ökologischen Landbau Untersuchungen diesbezüglich fehlen, wurde auf der Hessischen Staatsdomäne in Frankenhausen ein Feldversuch zu reduzierten Bodenbearbeitungssystemen angelegt. Die reduzierten Systeme sind das Dammkultur-System nach Turiel und das Ecomat-System der Firma Kverneland, welche dem herkömmlichen Pflug-System gegenüber gestellt werden. Die Dammkultur ist geprägt durch ihre konvex gewölbte Bodenoberfläche. Ihre Ausprägung hat einen möglicherweise Einfluss auf die räumliche Verteilung der mikrobiellen Biomasse, welche zu lokalen Unterschieden in der mikrobiellen Aktivität führt. Das Dammkultursystem mit mehrjährig konventionell bewirtschafteten Dämmen wurde intensiv u.a. im amerikanischen Mais-Gürtel (Corn Belt) untersucht. Im Gegensatz hierzu, wurde bisher kaum ein ökologisch bewirtschaftetes Dammkultur-System mit einjährigen Dämmen beschrieben, zu welchen das Turiel-System zählt. Dies führte zum Fehlen wissenschaftlich fundierter Daten, die als Grundlage für eine Bewertung und Diskussion des Systems nötig sind. Diese Wissenslücken ansatzweise zu schließen, ist Ziel vorliegender Arbeit. Hierbei soll das Dammkultur-System nach Turiel mit dem Pflug-System hinsichtlich folgender Gesichtspunkte verglichen werden: (1) der Erfassung bodenphysikalischer und bodenbiologischer Eigenschaften sowie deren räumliche Verteilung in gepflügtem und gehäufelten Boden; (2) die Messung der CO_2 Freisetzung. Außerdem wurden drei *in situ* CO_2 Messmethoden hinsichtlich ihrer Eignung für den Einsatz im Feld bewertet; (3) der Möglichkeit der Übertragung einiger untersuchter positiver Eigenschaften der mehrjährig genutzten Dammkultur auf das einjährige Dammkultursystem nach Turiel. Abschließend sollen der quantitative Vergleich der Erträge und eine qualitative Gegenüberstellung der

Inhaltsstoffe im Erntegut (Pflug, Dammkultur, Ecomat) zu weiteren Erkenntnissen beitragen.

Für die Untersuchung der bodenphysikalischen und bodenbiologischen Eigenschaften wurden Bodenproben entnommen. Die Bestimmung der Lagerungsdichten in gepflügten Parzellen erfolgte in den Tiefen 5, 15 und 25 cm. In den Dämmen wurde unter der Krone und der westlichen Furche in den Tiefen 5, 15, 25, 35/30 cm, von der Bodenoberfläche aus, beprobt. Die Probenahmen zur Bestimmung der mikrobiellen Biomasse, des anorganischen Stickstoffs und des Bodenwassergehaltes wurden im Pflanzenbestand mit einem Bohrstock in 10 cm Schritten bis in 30 cm Bodentiefe durchgeführt. Die gewölbte Oberfläche der Dämme wurde durch Markieren von 9 Beprobungspositionen mit einem Abstand von jeweils 10 cm (Luftlinie) auf dem Damm berücksichtigt. Die Bezugshöhe für die Probenahme war die Oberfläche der Pflugparzellen. Die CO_2 Freisetzung oder auch Bodenatmung zur Bestimmung der mikrobiellen Aktivität wurde mit einem mobilen Infrarot-Gasmessgerät (CIRAS) auf bewachsenem und unbewachsenem Boden bestimmt. Hierfür wurde an fünf Positionen auf dem Damm und auf den Pflugparzellen gemessen. Anschließend wurde die kumulative CO_2-Produktion für die Messdauer von 57 Tagen berechnet. Dabei musste die vergrößerte Oberfläche der unbewachsenen (+ 878 m²) und der bewachsenen Dämme (+ 434 m²) im Vergleich zu einem Hektar ebenen Ackerlandes kalkuliert und beachtet werden.

Die Untersuchungen des Freilandvergleichs der drei CO_2 Messmethoden fanden auf dem Reinshof, dem Versuchsgut der Universität Göttingen statt. Dabei wurden eine statische Haube, dieselbe statische Haube mit integriertem Lüftermodul (dynamische Haube) und das CIRAS als weitere dynamische Haube miteinander verglichen. Die in den Boden gedrückte statische Haube besteht aus einem PVC Rohr mit passendem Endstück. Die Gasproben wurden im Labor mit einem Gaschromatographen analysiert. Das CIRAS analysierte die Menge an entströmten CO_2 direkt vor Ort.

Um die auf der Hessischen Staatsdomäne erzielten Erträge (Pflug, Dammkultur und Ecomat) bewerten zu können, wurden die Erträge der Wintergerste (2006, 2008), Sommerweizen (2007), Ackerbohne (2007) sowie Kartoffeln (2008) bestimmt und ins Verhältnis gesetzt. Die folgenden Inhaltsstoffe wurden im Erntegut

(Wintergerste 2006, 2008; Sommerweizen 2007, Ackerbohne, 2007) mit der Nahinfrarotspektroskopie bestimmt: Rohprotein, Rohfett, Rohfaser, Stärke und Gesamtzucker. Die gemessenen Werte wurden an Hand der Futterwerttabelle (Deutsche Landwirtschafts-Gesellschaft) beurteilt. Die Lagerungsdichte in Pflug- (1.3-1.6 g cm^{-3}) und Dammparzellen (Krone: 1.0-1.4 g cm^{-3}) zeigte einen Tiefengradienten und erreichte ihr Maximum zwischen 1,5 und 1,6 g cm^{-3}. Grundsätzlich lag die Lagerungsdichte in der Krone und den Flanken der Dämme 0,2 bis 0,1 g cm^{-3} unterhalb der der Furchen und der des Pflug-Systems. Diese Unterschiede verschwanden mit der Tiefe und während der Wachstumsperiode. Auf gepflügten Parzellen blieben die Gehalte an mikrobiellem C und N über alle Tiefen relativ konstant bei 215 und 33 µg g^{-1} Boden (10-30 cm). Das C/N-Verhältnis der mikrobiellen Biomasse lag bei circa 6,4 und der Anteil an anorganischen Stickstoff reichte von 4.6 mg kg^{-1} Boden (Juli, 20 cm Tiefe) bis 11.1 mg kg^{-1} Boden (Mai, 30 cm Tiefe). Der Bodenwassergehalt lag zwischen 15% (Juli, 30 cm Tiefe) und 19% (Mai, 0-10 cm Tiefe). In den Dammkultur-Parzellen zeigten mikrobiell gebundene Biomasse C und N, der anorganische N und der Bodenwassergehalt räumliche Variabilität. Die höchsten Gehalte (Juli, 300 µg g^{-1} Boden) an mikrobiell gebundenem C wurden in den Kronen und die niedrigsten (Mai, 85 µg g^{-1} Boden) in den Furchen gemessen. Das durchschnittliche C/N Verhältnis der mikrobiellen Biomasse lag bei 6,5. Die Gehalte an anorganischem N lagen zwischen 3,1 mg kg^{-1} (Furche, Juli) und 27,8 mg kg^{-1} (Krone, Mai). Der anorganische N zeigte eine signifikant lineare Beziehung zum Wassergehalt.

Während der Untersuchungsdauer von 57 Tagen setzten die gepflügten Parzellen 9% (0.11 t CO_2-C ha^{-1}) mehr CO_2 je Hektar frei als die gehäufelten Parzellen. Jedoch ist zu beachten, dass die Anzahl der Bodenbearbeitungsmaßnahmen in der Dammkultur sechs und die auf den Pflugparzellen nur vier betrug, wodurch ein zusätzlicher CO_2 Ausstoß verursacht wurde. Auf Grund der räumlichen Variabilität der Lagerungsdichten, des Bodenwassergehaltes und der mikrobiellen Biomasse in den Dämmen wies auch die Messung der mikrobiellen Aktivität räumliche Unterschiede auf. Die mittlere Bodentemperatur (5 cm Tiefe) war in den gehäufelten Parzellen 0,1°C höher als in den gepflügten.

Die im Durchschnitt gemessene CO_2 Freisetzung der drei Methoden stieg

signifikant um 40%, beginnend bei der statischen Haube über die dynamische Haube bis hin zum CIRAS. Das CIRAS zeigte dabei die konstantesten Werte an, da es nicht auf Schwankungen der Boden- und Lufttemperatur reagiert. Hinzu kommt, dass das CIRAS leicht zu bedienen ist und mehrere Messungen in kurzen Zeitintervallen möglich sind. Die statische und dynamische Haube bedürfen eines höheren Aufwands. Zum Einen bei den Vorbereitungen und Messungen im Feld, zum Anderen bei den Analysen mit dem Gaschromatographen.

Das Dammkultur-System erzielte im Mittel über alle Fruchtarten 23% (2,4 t) und das Ecomat-System 3% (0,6 t) niedrigere Erträge verglichen zum Pflug-System (10,5 t). Diese Erträge, bezogen auf die CO_2 Freisetzungen je Hektar und Tag, zeigen, dass bei der Erzeugung einer Tonne Ackerbohnen 0,038 t CO_2 von den gehäufelten und nur 0,018 t CO_2 von den gepflügten Parzellen entweichen.

Die Inhaltsstoffe des Erntegutes zeigten signifikante Unterschiede zwischen den Bodenbearbeitungssystemen in: Rohprotein (Wintergerste 2006, Sommerweizen 2007), Rohfett (Wintergerste 2006, 2008), Stärke (Wintergerste 2006, 2008) und Gesamtzucker (Wintergerste 2006, 2008). Die Gehalte der Inhaltsstoffe von Pflug- und Ecomat-System ähnelten sich im Gegensatz zum Damm-System stark. Insgesamt zeigte das Bodenbearbeitungssystem keinen einheitlichen Einfluss auf die Quantität der Inhaltsstoffe im Erntegut. Verglichen mit den Futterwerttabellen überstiegen die Werte der Messungen für Rohprotein (Gerste, Weizen), Rohfaser (Gerste), Stärke (Gerste, Weizen, Ackerbohne) und Gesamtzucker (Ackerbohne) die vorgegebenen. Die Messwerte der anderen Fruchtarten unterschritten die der Futterwerttabellen. Kein einheitlicher Trend, außer bei Stärke, welche permanent unter den vorgegebenen Werten lag, wurde deutlich.

Aus den Ergebnissen der Vergleichsstudie zwischen Dammkultur-System und Pflug-System kann Folgendes geschlossen werden:

- Das Dammkultur-System führt im Gegensatz zu dem Pflug-System zu starken räumlichen Verteilungen in Lagerungsdichte, Bodenwassergehalt, anorganischen Stickstoff und mikrobiell gebundenem Kohlenstoff und Stickstoff. Dies resultierte nicht in höheren Erträgen oder qualitativ höheren Inhaltsstoffen.

- Die mittlere Bodentemperatur war in den Dämmen 0,1°C höher als im ebenen Boden der Pflugparzellen.
- Die CO_2 Freisetzung, umgerechnet auf eine Tonne Ertrag, war auf den gehäufelten Parzellen 53% höher als auf den gepflügten.
- Die erzielten Erträge (2006-2008) des Dammkultur-Systems lagen deutlich unter denen des Pflug-Systems.
- Die Gehalte an Inhaltsstoffen im Erntegut lagen in der Dammkultur ebenfalls unter denen des Pfluges.
- Bezug nehmend auf Metzke et al. (2007) war die Anzahl der Regenwürmer in den Dammparzellen signifikant weniger verglichen zu den Pflugparzellen.

Ausgehend von diesen Fakten sind die untersuchten potentiell positiven Eigenschaften der mehrjährigen Dammkultur nicht auf das einjährige Dammkultur-System nach Turiel zu übertragen. Die Untersuchungsergebnisse des Bodenbearbeitungsversuches auf der Domäne Frankenhausen zeigen, dass das Dammkultur-System nach Turiel keine adäquate Alternative zum Pflug im Ökologischen Landbau ist.

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