Project Title: Determining the causes of mushroom water stress symptoms

Project Number: M 35

Project Leader: Ralph Noble

Report : Final Report (May 2000)

Key Workers: Ralph Noble, Andreja Dobrovin-Pennington

Location of Project: Horticulture Research International
Wellesbourne, Warwick, CV35 9EF

Project Co-ordinator: Mr David Spurdens,
Tas Valley Mushrooms Ltd,
Norwich, Norfolk, NR12 7NG

Date Project Commenced: 1 May 1999

Date Project Completed: 30 April 2000

Keywords: Mushrooms, Casing, Compost, Water Stress, Disorders

CONTENTS

PRACTICAL SECTION FOR GROWERS

Objectives and Background

The occurrence of water stress symptoms can significantly reduce the marketable quality of mushrooms or result in the produce being unmarketable. Since the mushroom obtains water from both the casing and compost, the aim of the project was determine whether the availability of water from either or both of these sources could contribute to the occurrence of water stress symptoms. This was achieved by growing mushrooms in compost with a range of moisture contents, different watering regimes, two different casing materials (milled brown peat and bulk black peat) and different humidities during cropping.

The availability of water from the compost and casing was measured electronically using tensiometers and ThetaProbes which measure the water tension (matric potential) and volumetric water content. These electronic probes were also used on four farms to test their suitability for diagnosing water stress problems.

Summary of Results

- **Mushroom water stress symptoms**

The seven main stress symptoms observed were those in Fig.1 as well as misshapen and brown core mushrooms. Hollow and watery flesh mushrooms were most prevalent in wet and medium moisture casing but were unaffected by compost moisture. Mushrooms with water soaked-soaked blemishes on the caps were most prevalent in wet casing and dry compost. The percentage of watery caps from this combination of casing and compost moisture was higher at high humidity (17% of mushrooms affected) than at low humidity (8% affected). The highest percentages of distorted mushrooms were found in medium moisture compost in combination with wet or medium moisture casing, and in wet casing and compost. Leggy mushrooms were mostly on dry casing and were unaffected by compost moisture. The incidence of brown core was low (generally less than 1%) but there was some evidence that this was higher when a wet watering regime was used on bulk black peat casing. The general incidence of misshapen mushrooms was also less than 1%, but dry compost with a dry or medium watering regime on bulk black peat casing increased this to 5%. Casing type did not significantly affect the occurrence of the other stress symptoms.

- **Mushroom size**

Milled brown peat produced a higher proportion of small button mushrooms than bulk black peat casing. A wetter casing produced significantly heavier mushrooms at the same stage of development than a dry casing. Compost moisture did not have a consistent effect on mushroom weight.

- **Mushroom dry matter content**

Dry matter was significantly higher in mushrooms grown on a dry casing than on wet or medium moisture casing. Mushrooms with the lowest dry matter content were grown on wet compost with wet or medium moisture casing. Casing type and cropping room humidity did not affect dry matter content.

- **Mushroom yield**

An intermediate watering regime produced the highest yield in both casing types but yield from milled brown peat was higher using a drier compost than with bulk black peat. Fluctuating watering regimes (wet pre-flush or post-flush) produced lower yields than a constant watering regime.

- **Measurements of casing and compost water with electronic probes**
  Watering patterns on different farms and in different crops can be monitored with electronic tensiometers. Periods with over-wet or dry casing can be related to the occurrence of water stress symptoms such as watery flesh or leggy stems.

Action Points for Growers

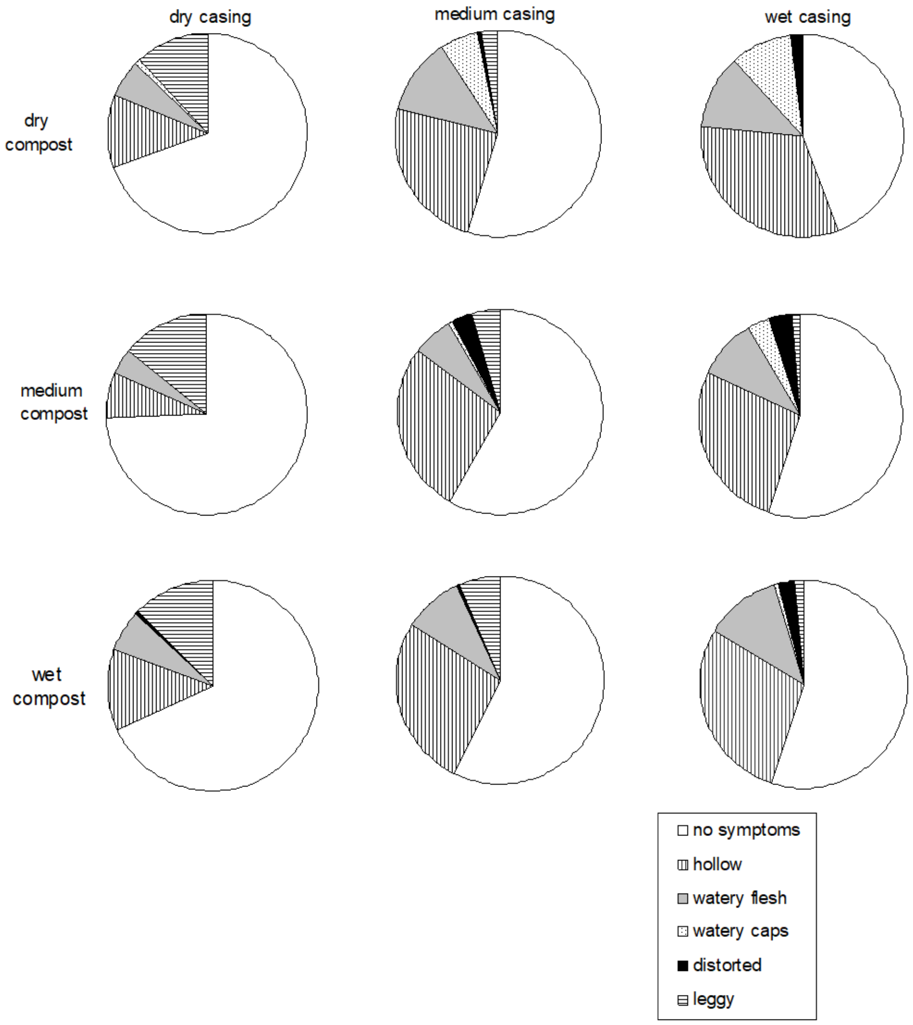
- The incidence of hollow and watery flesh mushrooms can be reduced by lowering casing moisture. The optimum casing moisture content will vary according to the material used.
- Mushrooms with watery blemishes on the caps are caused by a combination of wet casing on dry compost. Reducing cropping room humidity from 95% to 85% will also reduce this problem.
- Severely distorted mushrooms (split stems, 'sagging socks', distorted caps) are most prevalent on wet compost and wet casing, particularly between flushes.
- 'Leggy' mushrooms can be reduced by increasing casing moisture.
- The use of milled brown peat will increase the number of initials and small button mushrooms. A wet watering regime using a bulk black peat will reduce the number of small mushrooms and increase average mushroom weight.
- The optimum moisture content of spawn-run compost (in terms of mushroom yield) was 71% using a bulk black peat casing. With milled brown peat casing, a lower compost moisture content was better.
- Watering of the casing layer should be consistent throughout the crop since fluctuating watering regimes reduced mushroom yield significantly.
- Brown-core in mushrooms may be aggravated by using a wet watering regime on bulk black peat casing but further work, aimed specifically at this problem, is needed.
- Electronic tensiometers and ThetaProbes in casing and compost can be used to diagnose the causes of particular water stress symptoms on farms.

Practical and Financial Benefits to the Industry

The work has identified individual compost, casing and environmental factors, as well as combinations of factors, which are responsible for causing particular water stress symptoms in mushrooms. Using this information, practical steps can be taken to reduce the incidence of a particular stress related problem and improve crop yield and quality.

Information from electronic tensiometers and ThetaProbes in the compost and casing can be compared with values for 'normal' crops, and related to the occurrence of particular water stress problems. By monitoring farms using these probes, it should be possible to diagnose the causes of particular symptoms, and recommend changes to the crop husbandry.

Fig. 1 Effect of casing and compost moisture on the percentage of different water stress symptoms



SCIENCE SECTION

1. INTRODUCTION

The occurrence of water stress symptoms can significantly reduce the marketable quality of mushrooms or result in produce being unmarketable. The proportion of a commercial crop affected by water stress symptoms may be as high as 100% but it is likely that, on average, about 1% of the crop is down-graded or rendered unmarketable due to water stress symptoms. During the course of HDC Project M20a 'The effects of casing materials and casing management techniques on the yield and quality of mushrooms', it was noted that as a result of the watering regimes, some of the treatments produced mushrooms with various water stress symptoms. The mushrooms could allocated to the following categories, which include a range of disorders which may be related to the movement of water into or from the surface of developing sporophores: (1) no symptoms (2) severe distortions in which the cap or stipe tissue is split or divided vertically and horizontally (3) hollow mushrooms, either in the cap or stipe (4) watery marks visible on the cap or (5) in the cut flesh (6) misshapen or irregular cap development (7) 'weeping mushrooms' in which water droplets are exuded from the cap (8) 'leggy' mushrooms with elongated stipes in relation to cap size and (9) brown discoloration in the centre of the stipe and (10) scales, in which the surface tissue fails to grow, while the underlying tissue develops further (Fletcher et al, 1986; Geels et al, 1988; Hermans, 1988). Apart from the latter disorder, which is due to excessive evaporation from the cap surface, the exact causes of these disorders is unknown.

Mushrooms obtain water from both the compost and the casing, the proportion obtained from the casing has been found to vary between 36% and 83% depending on the availability of water from the two layers (Kalberer,1990; Harper, 1991). As a result of Project M20a, techniques were developed for measuring the volumetric water content and the availability of water in the compost and casing on a continuous basis. The volumetric water content can be measured with impedance measuring probes (ThetaProbes, Delta-T Devices Ltd, Cambridge, UK) and the availability of water or 'matric potential' can be measured using electronic tensiometers (Delta-T Devices Ltd). The aims of this project were: (1) determine the influences of compost and casing water and evaporation rate on the occurrence of water stress symptoms (2) measure the amount and availability of compost and casing water electronically and relate these to the occurrence of stress symptoms (3) relate the experimental measurements with tensiometers and ThetaProbes with measurements under commercial conditions.

2. MATERIALS AND METHODS

2.1 Experimental work

2.1.1 *Experimental treatments*

The treatments are summarised in Table 1. Spawn-run composts with three different moisture contents were used. These were prepared by adjusting the water application during the initial windrow composting before pasteurisation (Noble et al, 1998). Wooden cropping trays (0.9 x 0.6 x 0.2[deep]) were filled with 50 kg spawned compost (48 kg spawn-run compost) which was spawned with the strain A15. Sugar beet lime (SBL) was mixed with the peat types (milled brown or bulk black) at 250 kg m^{-3} casing. The matric potential treatments in the experiments were maintained by adjusting the water application in the initial mixing of the casings, and by adjusting watering after application of the casings to the cropping trays.

The air in the cropping rooms was recirculated and the relative humidity maintained at 95-98% until mycelial growth in the casing layer had become established, 6-8 days after application. Fresh air was then introduced into the growing room and the relative humidity reduced (Table 1). Two replicate cropping rooms were used for each of the two humidity treatments and each of the four rooms contained a single tray of each casing soil x compost treatment. The trays were arranged in a randomised block design. Evaporation rate in the rooms was measured with Piche evaporimeters (Fletcher et al, 1986).

Table 1. Experimental treatments

Variable	Treatments
Peat extraction method/ decomposition	milled brown or bulk black
Casing matric potential*, kPa	-36, -7, -3 (dry, medium, wet)
Spawn-run compost moisture content, %	62, 71 or 76 (dry, medium, wet)
Watering pattern	uniform, wet pre-flush or wet post-flush
Cropping chamber r.h. after airing, %	84-86 or 94-96

*average value during the crop

2.1.2 *Properties of peat types and casing soils*

The following physical and chemical analyses were conducted on the peat and casing soil samples before and after use for mushroom culture: air filled porosity (AFP), bulk density, pH and EC (Noble et al, 1999). Ash and dry bulk density were also conducted on the peat samples. Water retention characteristics of peat and casing soil samples were determined using a modified method from Noble et al (1999), based on a water tension table constructed from Bucnher funnels. Peat or casing soil samples at near saturation were filled into metal rings (depth 50 mm, internal diameter 70 mm) which had a muslin base attached. Each ring was placed on to a 10 mm depth bed of kaolin in the base of a 250 mL Buchner funnel. The water in the kaolin and base of the funnel formed a continuous reservoir with a water filled rubber 'U' tubing attached to the funnel. Sample desorption characteristics could then be determined by gradually lowering the free end of the tube and reducing Ψ_m of the samples to - 36 kPa (Noble et al, 1999).

Casing matric potentials (water tensions) were measured by taking 100 g casing samples from the plots at two-daily intervals and determining the moisture content by oven drying. The moisture contents were then converted into water tensions by using a calibration curve for each casing material. The calibration curves were obtained by using the above Buchner funnel method. Casing matric potentials were also measured directly using electronic tensiometers as described below.

2.1.3 *Matric potential and water content of casing soil and compost in the cropping trays*

Miniature electronic pressure transducer tensiometers (type SWT5, Delta-T Devices Ltd, Cambridge, UK) connected to a logger (type DL2e, Delta-T Devices Ltd) were used to monitor casing soil matric potential Ψ_m (Noble et al, 1999). Compost Ψ_m was also monitored using electronic pressure transducer tensiometers (type SWT3, Delta-T Devices Ltd). The 50 mm length, 20 mm diameter porous cap of the tensiometer was positioned centrally in the compost, through a vertical 22 mm hole in the compost and casing layer, which was filled with quartz powder paste to ensure good water contact between the porous cap and the compost.

Compost and casing soil volumetric water content θ_v were monitored using electrical impedance measuring probes (ThetaProbes type ML1, Delta-T Devices Ltd). The probes were positioned vertically with the tips positioned centrally in the casing soil or compost.

2.1.4 *Crop records and quality defects*

Where possible, mushrooms were picked with the veils closed at a diameter of 35 – 45 mm, over a 23 day period (3 flushes) with the first flush being picked *c.* 17 days after the application of the casing soil. On some treatments, due to overcrowding of mushrooms or premature opening, mushrooms had to be picked with a smaller diameter or with the veils open. The percentage dry matter and weight of twenty 45mm diameter (stage 3) mushrooms from each tray and flush were determined according to Burton & Noble (1993). The number of mushrooms in the following categories were recorded in 40 mushrooms from each plot and flush:

(1) no symptoms
(2) severe distortion (mushrooms with divided or split tissue in the cap and/or stipes)
(3) hollow mushrooms, either in the pileus or stipe
(4) watery marks visible on the cap
(5) watery marks visible in the cut flesh
(6) misshapen (irregular or asymmetrical cap and/or stipe development)
(7) 'weeping mushrooms'
(8) 'leggy mushrooms' with elongated stipes in relation to cap size
(9) brown discoloration in the centre of the stipe.

Mushrooms generally did not exhibit more than one of the symptoms in categories (2) to (8). A small number of mushrooms exhibited combinations of symptoms in categories (2) to (6); in these instances, only the more severe symptom (lower category number) was recorded. Mushrooms in category (9) were recorded separately. Photographs of mushrooms in each category are shown in the Appendix.

2.2 On-farm measurements

2.2.1 *Farms visited*

Measurements were taken on four different mushroom farms with different growing systems and/or casing materials. Details of the growing systems, compost type, casing materials and mushroom strains used on the farms visited are shown in Table 2.

2.2.2 *Crop records*

Casing matric potential and compost volumetric water content were measured using electronic tensiometers and ThetaProbes as described in Section 2.1.3. Compost and casing samples were obtained after casing, before and after the first flush, and at the end of the crop. Casing materials were analysed for physical and chemical properties as described in Section 2.1.2.
Daily yield records were obtained for each crop and the presence of any quality defects recorded.

Table 2. Details of mushroom farms, composts and casing materials

Farm	Growing system	Compost	Casing material	Casing depth, mm	Strain
A	blocks	Phase III	McArdle ready mix 3:1 Irish black bulk peat: Irish milled brown peat + 13% SBL	65	Amycel 2100
B	trays	Phase II	1:1 Irish : Finnish milled brown peat + 30% lump chalk	47	Sylvan A15
C	blocks on shelves	Phase II	L & P ready mix Black peat + SBL	55	Amycel 2200
D	trays	Phase II	Harte ready mix Black + brown peat + SBL	50	Sylvan A15

3. RESULTS

3.1 Experiment in cropping chambers

3.1.1 *Properties of peat types, casing materials and composts*

The milled brown peat used in the experiment had a lower pH than the bulk black peat (Table 3) but the pH values of the casing mixes after addition of lime were similar (Table 4). The ash content and dry bulk density of the milled brown peat were lower than those of the bulk black peat (Table 3). The milled brown peat had a lower moisture content before addition of water, but the total water retention of the milled brown and bulk black peats were similar (Table 3). After addition of lime, the milled peat casing had a slightly higher water retention than the bulk black peat casing (Table 4).

Table 3. Properties of peat types used in the experiment

Peat type	pH	EC uS	Moisture* % w/w	Ash % of d.m.	AFP** %	Dry bulk density g/l	Water retention % w/w
Milled brown	3.8	112	68.9	1.8	18.1	159	87.2
Bulk black	5.2	80	81.3	6.9	9.6	220	87.3

Table 4. Physical and chemical properties of casing materials before and after use for mushroom culture. Mean of three casing moisture treatments

Peat type	pH		EC, uS		Water retention, % w/w		AFP, %		bulk density g/litre	
	before	after	before	after	before	after	before	after	before	after
Milled brown	7.3	7.6	666	1127	77.2	76.8	10.6	17.7	716	571
Bulk black	7.2	7.6	711	1047	72.6	72.1	12.2	22.8	767	613

3.1.2. *Effects of treatments on mushroom yield*

There were significant effects of compost and casing moisture and casing peat type on mushroom yield, and significant interactions between all three factors ($P<0.01$). For bulk black peat casing, the 'medium' compost and casing moisture treatments produced the highest mushroom yield; wetter or drier compost or casing moisture contents reduced mushroom yield (Fig.2). For milled brown peat casing, the medium casing moisture also produced the highest yield, but yield was greatest with the drier compost in combination with medium casing moisture (Fig.2).

The fluctuating watering regimes produced significantly lower yields than the medium, constant moisture regime (Fig.3). For bulk black peat casing, a wet pre-flush watering regime was more detrimental to yield than a dry pre-flush watering regime.

Cropping room humidity had no significant effect on mushroom yield, and there were no significant interactions between humidity and any of the other factors. Evaporation rate, measured with Piche evaporimeters, was 0.2 and 23.3 g water/ m^2/ day in the high and low humidity rooms.

3.1.3 *Effect of treatments on mushroom size*

Milled brown peat casing produced a higher proportion of small button mushrooms than bulk black peat casing. The highest proportion of small button mushrooms (29.5% of total yield) was produced on a milled brown peat casing, a dry pre-flush watering regime and a medium moisture compost. The lowest proportion of small button mushrooms (10.6% of total yield) was produced on a bulk black peat casing, a wet casing watering regime and dry compost.

A wetter casing produced significantly heavier stage 3 mushrooms (mean 24.2 g) and a dry casing produced significantly lighter mushrooms (mean 19.9 g) than the medium casing moisture treatment (mean 22.8 g). The lightest mushrooms (mean 17.5 g) were produced on a dry casing with a medium moisture compost. Average weight of stage 3 mushrooms was not significantly affected by the pattern of watering (fluctuating or constant), or cropping room humidity.

3.1.4 *Mushroom dry matter content*

Mushroom dry matter content was significantly higher in mushrooms grown on a dry casing than on wet on medium moisture casing (Fig.4). With wet or dry casing, compost moisture reduced mushroom dry matter content, but with medium

Fig.2 Effect of compost and casing moisture on mushroom yield

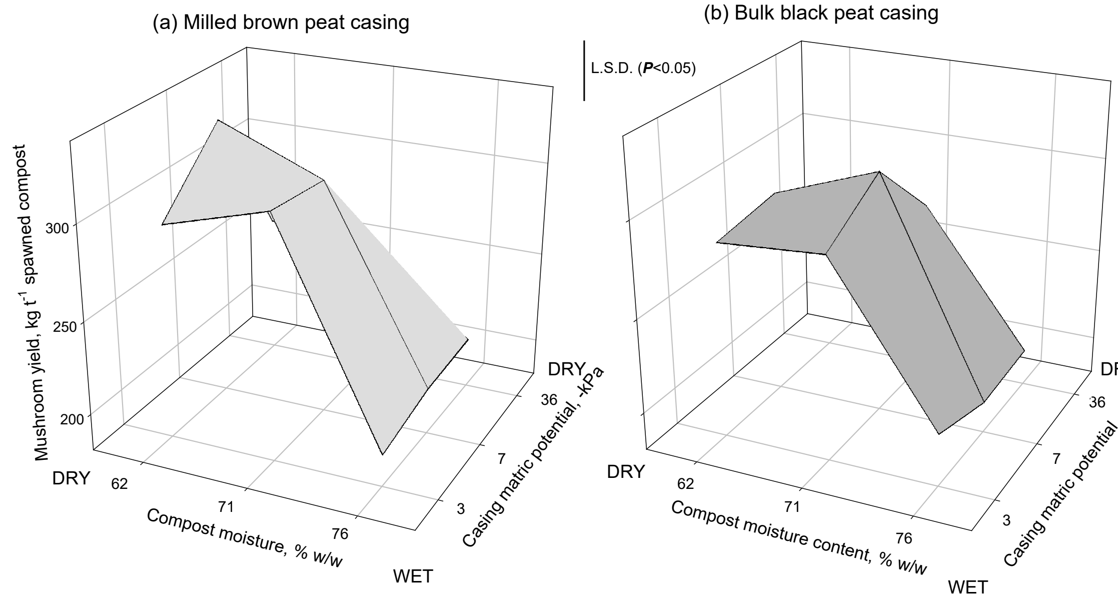


Fig.3 Effect of constant and fluctuating casing moisture treatments at different compost moistures on mushroom yield

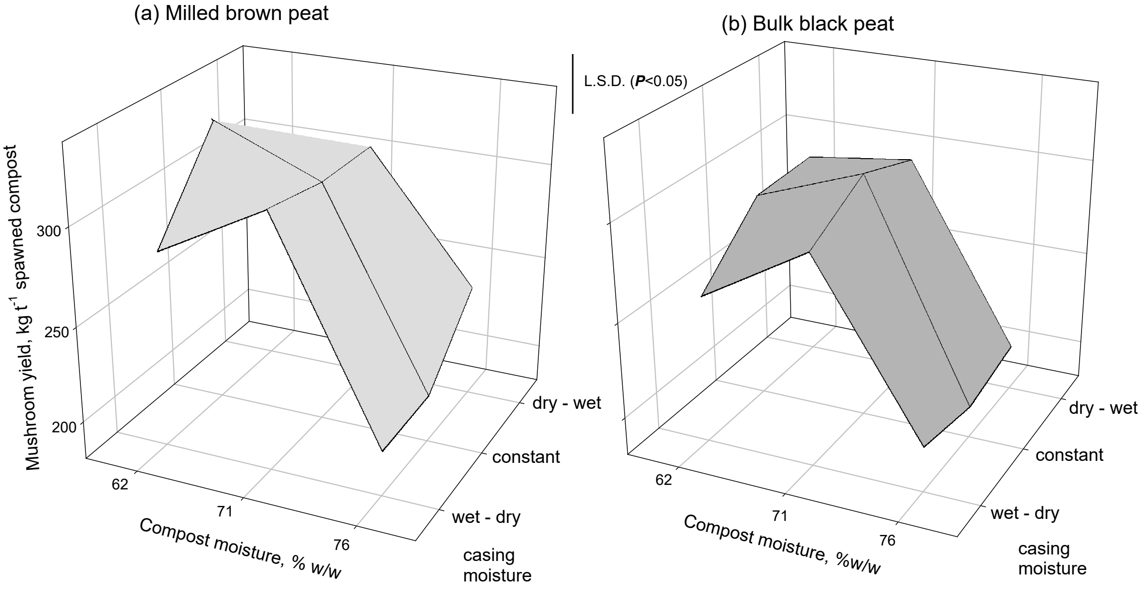
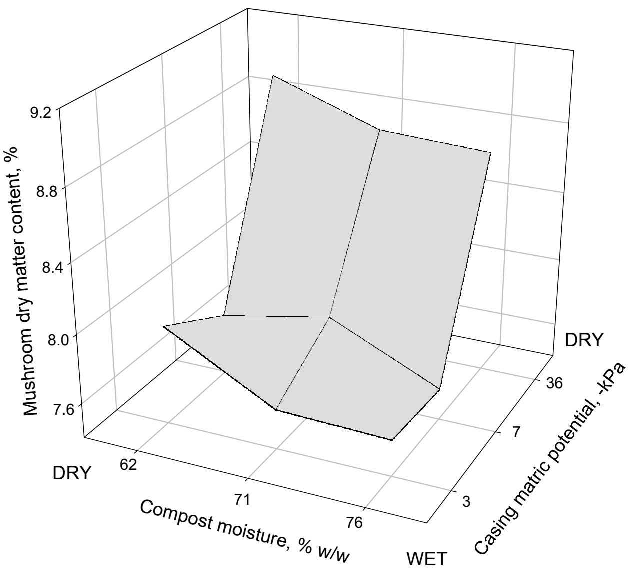


Fig.4 Effect of casing and compost moisture on mushroom dry matter content



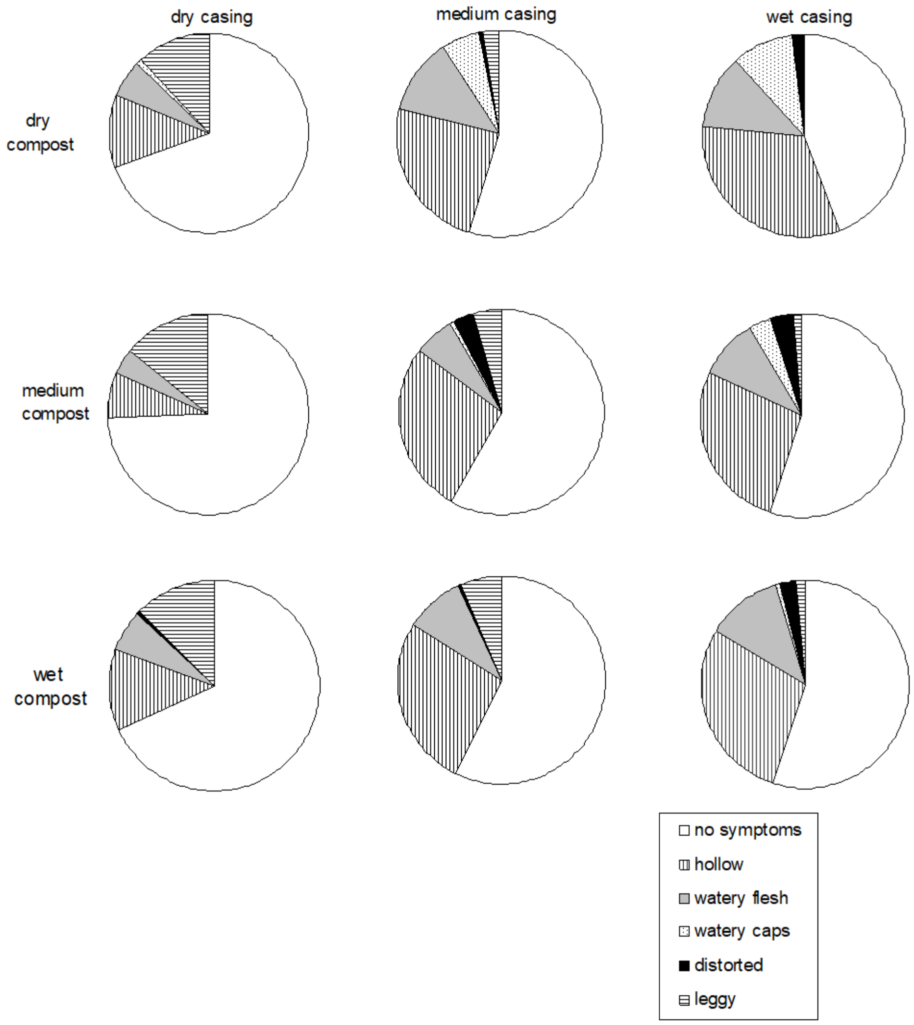
moisture casing, dry matter was highest with medium moisture compost (Fig.4). Mushrooms with the lowest dry matter content were grown on wet compost with wet or medium moisture casing. There were no significant effects of casing type or cropping room humidity on mushroom dry matter content.

3.1.5 *Mushroom water stress symptoms*

Photographs of the different stress symptoms are shown in the Appendix. The percentages of mushrooms with different stress symptoms are shown in Fig.5. Hollow and watery flesh mushrooms were most prevalent in wet and medium moisture casing, but were unaffected by compost moisture. Mushrooms with watery caps were most prevalent in wet casing and dry compost. The percentage of watery caps from this combination of casing and compost moisture was higher at high humidity (17%of mushrooms affected) than at low humidity (8 % affected). The highest percentages of distorted mushrooms were found in medium moisture compost in combination with wet or medium moisture casing, and in wet casing and compost. These were mainly found in mushrooms growing between the main flushes. Leggy mushrooms were mostly on dry casing and were unaffected by compost moisture.

In 45 out of 48 of the factorial treatment combinations, brown core affected less than 1% of the mushrooms. In the remaining three factorial treatments, brown core affected 2 - 2.5 % of the mushrooms and two of these factorial combinations included bulk black peat casing and a wet watering regime. However, insufficient numbers of mushrooms were affected with brown core to determine if this effect was significant. Less than 1% of mushrooms in all treatments were classified as misshapen, with the exception of those growing on bulk black peat casing with a dry or normal watering regime and dry compost (5% of mushrooms misshapen). 'Weeping' mushrooms were recorded on only two mushrooms from different treatments. Casing type (bulk black or milled brown peat) did not significantly affect the occurrence of the stress symptoms. There were no significant differences between the constant and fluctuating watering regimes in terms of the percentage of mushrooms affected with water stress symptoms.

Fig.5 Effect of casing and compost moisture on the percentage of different water stress symptoms



3.1.6 *Measurement of matric potential and water content of casing and compost in the cropping trays*

Matric potentials of the black bulk peat casing and wet, medium and dry watering regimes are shown in Fig. 6a. Matric potential decreased to less than -10, -30 and -50 kPa during each flush for the wet, medium and dry treatments. There were corresponding decreases in compost moisture content (Fig. 6b). Casing moisture contents determined from regular samples from the trays are shown in Fig. 6c, together with water applications in the three watering regimes.

Compost matric potential decreased to -6, -20 and -40 kPa in the wet, medium and dry compost treatments (Fig. 7a). Both the Tensiometer and ThetaProbe readings indicate a greater difference in moisture between the wet and medium treatments than between the medium and dry treatments, although the reverse was true. This was probably due to the non-linear relationship between these readings and compost moisture content (see right hand scale of Figs. 6b and 7b). Fluctuations in the ThetaProbe readings in Fig. 7b were caused by water applications and the mushroom flushes.

Fig.6 Tensiometer (a) ThetaProbe (b) readings and (c) moisture content and watering of wet, medium and dry casing treatments, medium compost moisture

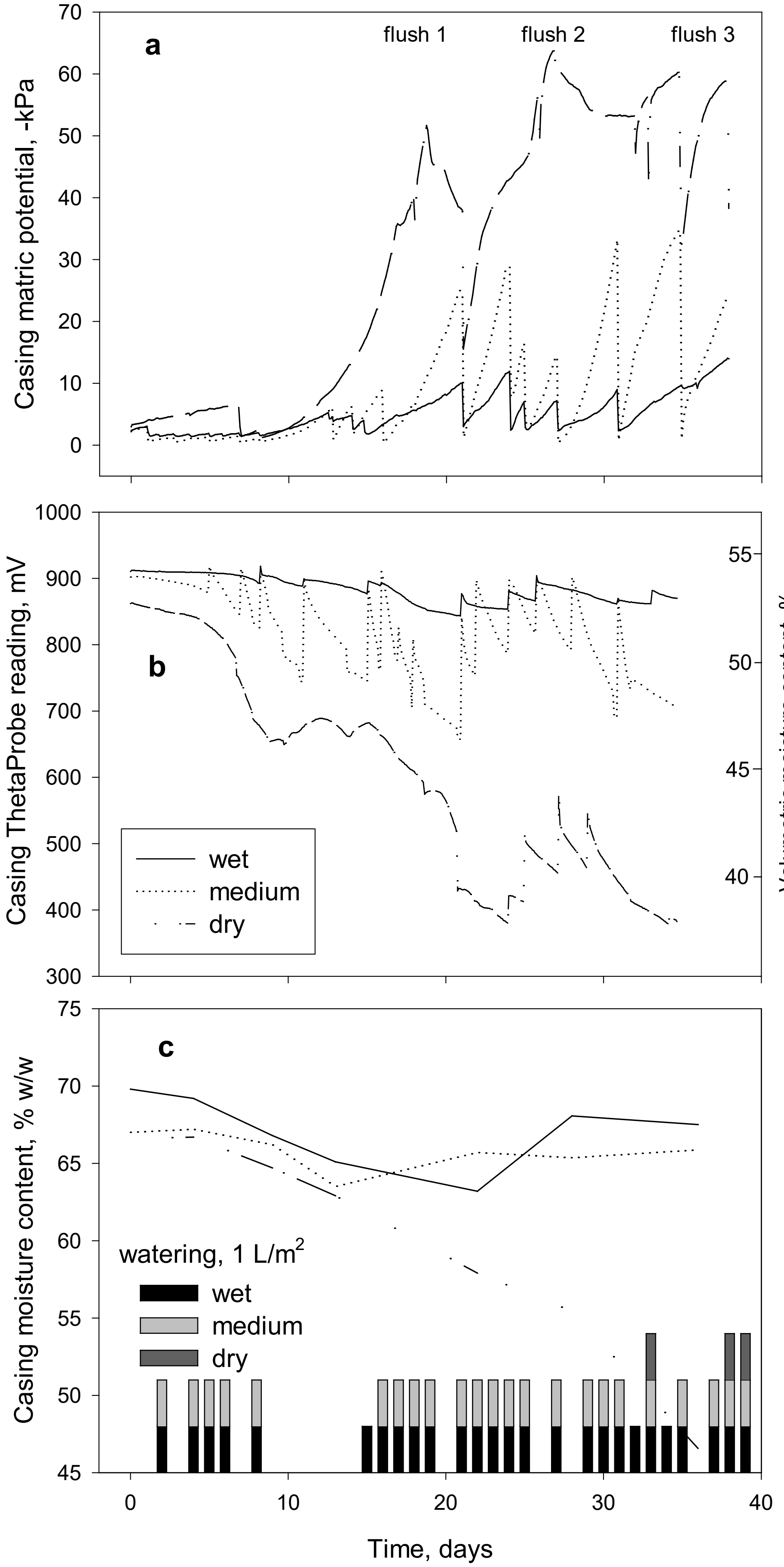
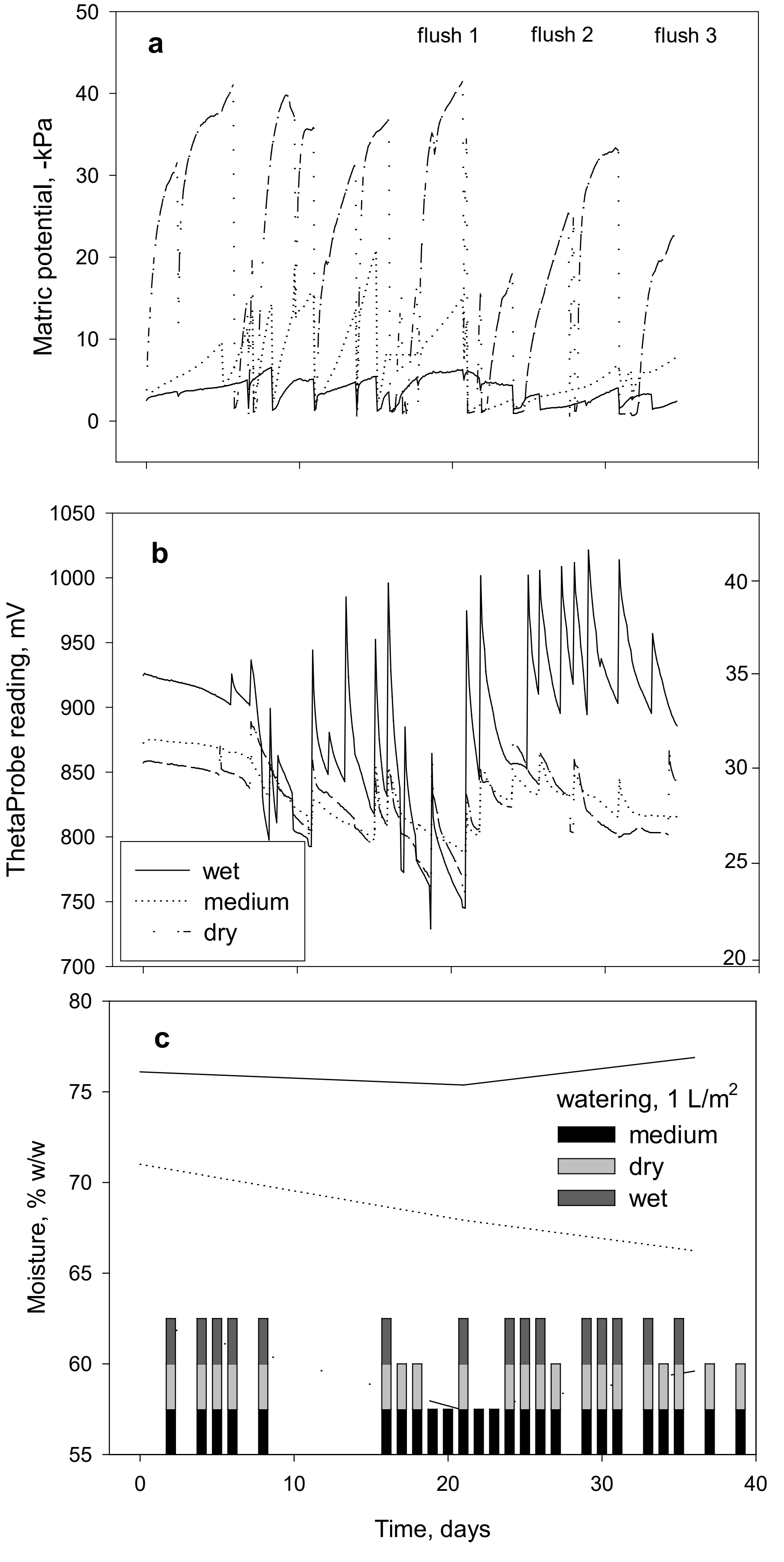


Fig.7 Tensiometer (a) and ThetaProbe (b) readings, moisture content and (c) watering of wet, medium and dry compost treatments, medium casing moisture



3.2 On-farm trials

3.2.1 *Properties of casing materials in on-farm trials*

Casing used on Farm B had a higher conductivity than the materials used on the other three farms (Table 6). This casing material also had a significantly lower bulk density, air filled porosity and water retention than the other materials (Tables 6 & & 7). Casing on Farm D had the highest water retention, both at saturation and under applied suctions. Casing water release curves are shown in Fig.8.

3.2.2 *Casing and compost moisture*

The gravimetric moisture content of the casing on Farm B was significantly lower than that on the other farms. However, due to the lower water retention of this material, the moisture content was kept much closer to saturation than on the other farms, i.e. small water tension (Fig.9, Table 7).

The average casing water tension during the entire cropping period was significantly greater in Farm D than on the other farms. Fig. 10 shows the matric potentials (water tensions) during cropping. The casing water tensions in flushes 1 and 2 were much smaller in Farms A and B than in Farms C and D. Farm B showed a large rise in water tension in the third flush. Compost on Farm B dried out more at the end of the third flush than on the other farms (Fig.9).

3.2.3 *Mushroom cropping pattern and water stress symptoms*

There were significant differences in the flushing pattern between farms, with Farm D having a significantly shorter flushing interval than Farms A and B. There were no crop records from Farm C since much of the crop was discarded due to over-pinning.

A large proportion of mushrooms on Farm A had watery marks in the cut flesh (Photo 5). This may be related to the small water tensions which developed in the casing (Fig.10). There were no obvious stress symptoms on Farm D and the first two flushes from Farm B, but the third flush had a significant number of mushrooms with short tapering stipes (Fig.8b) although they did not significantly affect marketable quality. The symptom may be related to the rapid drying out of the compost and casing at the end of the crop (Figs. 10 & 11).

Flush 1 mushrooms on Farm B had a significantly higher dry matter content than all the other samples (Table 8). This may be due to the lower moisture content of the casing on this farm.

Table 6. Properties of casing materials in on-farm trials

Farm	pH	conductivity µS	AFP %	Bulk density g/L
A	7.66	254	16.3	662
B	7.42	790	10.7	546
C	7.33	494	22.8	610
D	7.39	303	18.1	688

Fig.8 Water releases curves of casing from four farms

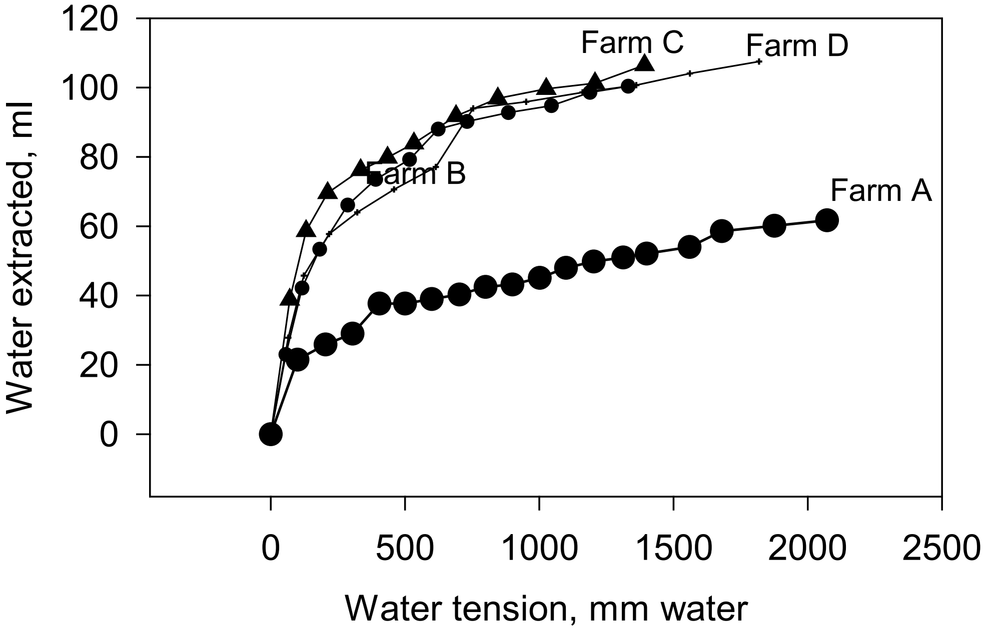


Table 7. Water retention characteristics of casing materials and average water tension (matric potential) during cropping.

	Water retention, % at:			Matric potential
Farm	Saturation	-5 kPa tension	-15 kPa tension	kPa
A	85.6	80.2	78.4	- 3.59
B	72.8	59.2	56.4	- 1.58
C	85.0	81.2	80.1	- 6.86
D	88.1	83.9	82.4	- 12.25

Table 8. Mushroom dry matter content

Farm	Flush 1	Flush 2	Flush 3
A	8.0	8.5	__
B	10.0	7.0	__
C	8.0	__	7.9
D	8.4	__	8.7

Fig.9 Casing and compost moisture contents and mushroom yield from four different farms

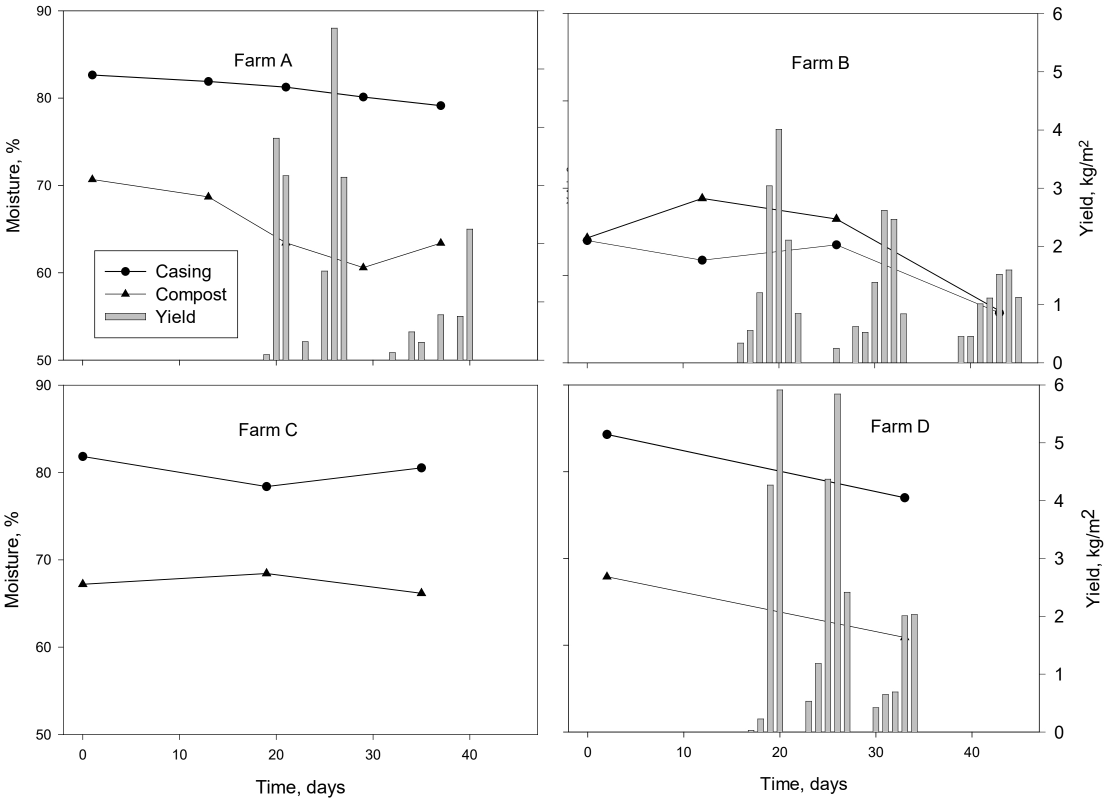


Fig.10 Matric potential of casing during cropping on four different farms

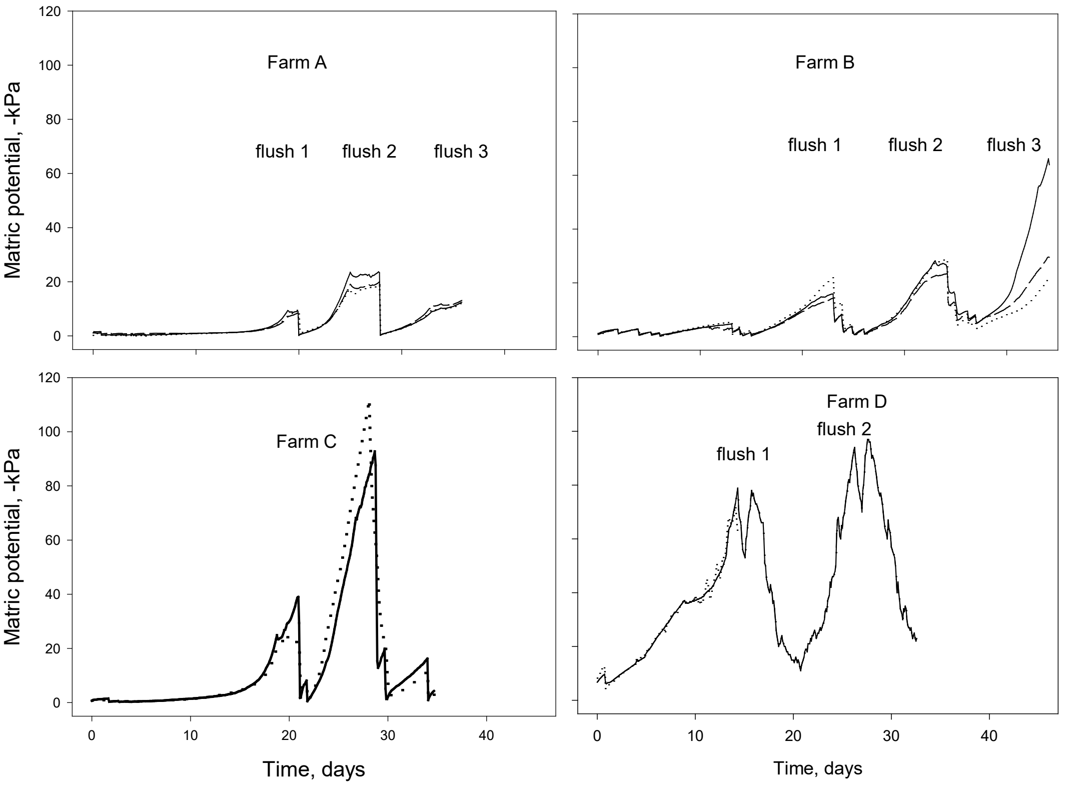
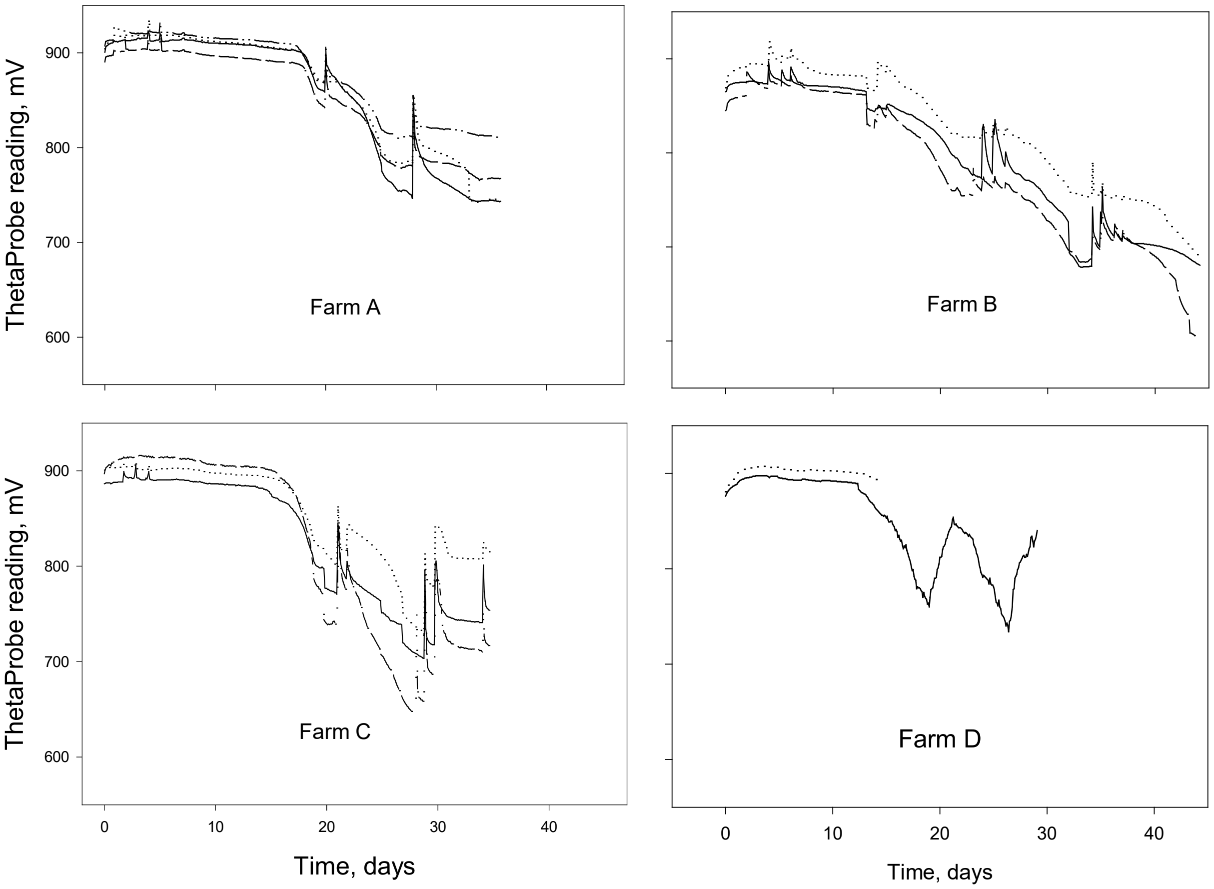


Fig.11 Compost volumetric moisture content measured with ThetaProbes



4. CONCLUSIONS

Different stress symptoms were produced in mushrooms growing in composts and casings with a range of moisture contents. Wet casing increased the proportion of hollow mushrooms and watery flesh mushrooms. This effect was confirmed in measurements on Farm A farm which used a deep layer of wet casing on a dry compost. The result partially confirms the view of Hermans (1988) that watery flesh is caused by evaporation problems, but dry compost also increases the problem. Mushrooms with watery blemishes on the caps were most prevalent in mushrooms grown in wet casing on a dry compost. This problem was exacerbated by growing mushrooms at higher humidity. Distorted mushrooms were generally more prevalent in wetter casing and compost. Leggy mushrooms were more prevalent in dry casing and were not affected by compost moisture. The incidence of brown core was low and fairly uniform, but there was some evidence that it may increase in very wet casing. This would require further investigation aimed specifically at this problem. Some of the mushrooms had white core centres; this indicates that brown core, which Richardson (1993) found associated with pseudomonad bacteria, may the result of a secondary infection of physiological tissue damage.

A symptom not found in the experiment, but found in the third flush at Farm B, were mushrooms with tapering stipes. Farm B had a 'wet' watering regime until the end of the second flush, after which the casing was allowed to dry out.

Casing type (bulk black or milled brown peat) or fluctuating watering regimes had little or no influence on the occurrence of stress symptoms. However, milled brown peat casing produced a higher proportion of small button mushrooms than bulk black peat casing. This confirms the result found in HDC Project M20a.

Bulk black peat casing produced the highest yield when spawn-run compost had a moisture content of 71%; milled brown peat casing produced a higher yield on drier spawn-run compost (62%). For both types of casing, there was an optimal matric potential (water tension) of about -7 kPa. On a gravimetric moisture content basis, this represented a higher moisture content for the milled brown peat casing than for the bulk black peat casing. This optimal matric potential was similar to that found previously (-8 to -10 kPa) in project M20a. Three of the farms visited (A,B and C) had a higher matric potential (smaller water tension) and Farm D had a lower matric potential (greater water tension) than this experimentally determined optimum. In the experiments, excessively wet casing had a more negative effect on yield than excessively dry casing.

Fluctuating watering regimes (wet or dry before flushes) produced a lower yield than a consistent watering regime. This confirms the results of Flegg (1975).

Records from four farms with different casing materials and growing systems showed significantly different patterns in casing water tension and compost moisture during cropping. A crop with a large proportion of watery flesh mushrooms on one of the farms coincided with the small water tensions in the (over-wet) casing. This confirms the results in the experiment which also showed that the problem was made worse by over-wet casing.

GLOSSARY

List of symbols and units used in the report

Symbol	Meaning
Ψ_m	matric potential or water tension
θ_v	volumetric water content
AFP	air filled porosity, expressed as % of total volume
EC	electrical conductivity
SBL	sugar beet lime

Unit	Meaning
kPa	kiloPascal, unit of pressure, 1 bar = 100 kPa negative values indicate suction or tension
uS	microSiemens, unit of electrical conductivity (EC)
mV	milliVolt, ThetaProbe output directly related to volumetric water content, 1100 mV = 100% v/v water

REFERENCES

Burton KS & Noble R 1993 The influence of flush number, bruising and storage temperature on mushroom quality. Postharvest Biology Tech. 3: 39 - 47.

Flegg P B 1975 The response of the mushroom crop to the pattern of watering. Scientia Horticulturae 3, 137 - 142.

Fletcher J T, White P F and Gaze R H 1986 Mushrooms: Pest and Disease Control. Intercept, Newcastle upon Tyne, UK. 156p.

Geels F P, van de Geijn J and Rutjens A J 1988 Pest and diseases. In: The Cultivation of Mushrooms (Ed LJLD van Griensven) Darlington Mushroom Laboratories, Sussex. UK. pp 361 – 419.

Harper E 1991 Energy and some consequences in mushroom cropping. Mushroom News 39 (10), 27–35.

Hermans C 1988 Climate and cultivation technique. In: The Cultivation of Mushrooms (Ed LJLD van Griensven) Darlington Mushroom Laboratories, Sussex. UK. pp 361 – 419.

Kalberer P P 1990 Water relations of the mushroom culture *Agaricus bisporus*: study of a single break. Scientia Horticulturae 41, 277–283.

Noble R, Gaze R & Willoughby N 1998 A high yielding substrate for mushroom experiments: Formula 3. Mushroom J. 587: 27 - 28.

Noble R, Dobrovin-Pennington A, Evered C E and Mead A 1999 Properties of peat-based casing soils and their influence on the water relations and growth of the mushroom (*Agaricus bisporus*). Plant and Soil 207: 1 – 13.

Richardson P N 1993 Stipe necrosis of cultivated mushroom (*Agaricus bisporus*) associated with a fluorescent pseudomonad. Plant Pathology 42: 927-929.

APPENDIX

Photographs of Stress Symptom Categories

Photo. 1 No stress symptoms

Photo. 2a Cap distortion

Photo. 2b Distortion - 'sagging or fallen-down socks'

Photo. 2c Distortion - split stipes

Photo. 3 Hollow mushrooms

Photo. 4 Watery marks visible on the cap

Photo. 5 Watery marks visible in the cut flesh

Photo. 6 Misshapen, irregular or asymmetrical cap development

Photo.7 Weeping mushroom

Photo. 8a 'Leggy' mushrooms

Photo. 8b Mushrooms with short, tapering stipes

Photo. 9a Brown core discoloration

Photo. 9b Severe brown core discoloration