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GrassVESS: a modification of the visual evaluation of soil structure method for grasslands

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Abstract

Visual evaluation of soil structure (VESS) is used for assessing arable management impact on soil quality. When used on pastures, operators have identified limitations because VESS does not consider a surface root-mat typical of managed grassland. The structure of the root-mat may be indicative of nutrient use efficiency, pollution potential and subsurface compaction. The objectives of this research were to develop GrassVESS for grassland soil management, to compare it with VESS and quantitative physical indicators and to assess its utility for soil management. GrassVESS maintained the methodological strengths of VESS, but uses a flow chart, grassland images and a new root-mat score. A focus group found GrassVESS to be quicker, dealt better with technical information and made root-mat evaluation easier. The range of structural quality scores assigned by the focus group for a site was less for GrassVESS than VESS, suggesting the procedure is more reproducible, thus suitable for use by a range of stakeholders. GrassVESS was also deployed at 30 grassland sites across Ireland. Results indicated that GrassVESS generated the same overall diagnoses as VESS, but the GrassVESS root-mat structural quality score was better related to bulk density, total porosity at 5–10 cm and a visual estimation of damaged sward area. It was concluded that GrassVESS has improved the VESS method for the specific assessment of grassland soil structural quality and could be used in real-time farm management decision support.

Keywords: Sustainable soil management, visual soil evaluation, grassland soil quality, root-mat evaluation, soil structure

Introduction

Visual soil evaluation (VSE) techniques are valuable for soil quality assessment (Mueller *et al.*, 2013; Askari *et al.*, 2015) and sustainable soil management (Shepherd, 2009; Ball *et al.*, 2017). Numerous procedures have been critically reviewed (Emmet-Booth *et al.*, 2016) involving the visual and tactile assessment of soil structure (Ball *et al.*, 2013). The visual evaluation of soil structure (VESS) method (Ball *et al.*, 2007; Guimarães *et al.*, 2011) has gained popularity (e.g. Munkholm *et al.*, 2013; Cui *et al.*, 2014; Cherubin *et al.*, 2017) and is known to correlate with physical (Guimarães *et al.*, 2011, 2013; Pulido Moncada *et al.*, 2014)

and biochemical (Askari *et al.*, 2015) soil quality indicators. VESS is easy to deploy (Guimarães *et al.*, 2013; Pulido Moncada *et al.*, 2014), with a five-point scale, and is usable by a range of stakeholders (Ball *et al.*, 2007).

VESS, and the Peerlkamp method from which it is derived (Ball *et al.*, 2007), focuses on tilled soil under arable management (Peerlkamp, 1959; Ball *et al.*, 2007). Peerlkamp (1959) noted the need for modification for grasslands, echoed by Cui *et al.* (2014). In pastures, the mechanisms of structural morphology differ due to the root development of a permanent crop, infrequent cultivation and the action of livestock. Compaction in tilled soils tends to be at depth due to heavy machinery, while annual tillage operations modify soil surface structure (Batey, 2009). Grassland compaction may result from machinery or livestock (Creamer *et al.*, 2010; Newell-Price *et al.*, 2013). Heavy machinery passes, notably on wet soils, may gradually cause compaction at

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depth. Livestock treading may cause surface poaching or pugging (Drewry, 2006). Such processes are linked with increased bulk density, shear and penetration resistance and changes in porosity (Kurz *et al.*, 2006; Herbin *et al.*, 2011; Phelan *et al.*, 2013), notably reductions in macro-porosity (Houlbrooke *et al.*, 2011). However, subsurface structural degradation may not be as visible as in arable soils (Roger-Estrade *et al.*, 2004).

Cui *et al.* (2014) identified problems using VESS in pastures where the grass root-mat was difficult to assess. This layer is the soil-atmosphere interface directly influencing infiltration and gaseous exchange (Alderfer & Robinson, 1947; Hillel, 1998), impacting soil functioning and pollution, notably nutrient run-off (Kurz *et al.*, 2006; Bilotta *et al.*, 2007) and greenhouse gas fluxes (Ball *et al.*, 2012; Ball, 2013). For example, Batey & Killham (1986) described nitrogen losses from anoxic zones directly below hoof prints. The root-mat is damaged directly by livestock treading (Nie *et al.*, 2001) and machinery operations, with compacting forces progressively transmitted downwards through the soil. Natural root-mat rejuvenation will occur (Drewry, 2006), however may take time (Herbin *et al.*, 2011). The recovery of subsurface structure is more gradual (Drewry, 2006); therefore, the root-mat and structure below can represent different morphological timescales. The root-mat evaluation indicates recent impacts, subsurface compaction likelihood, soil-atmosphere interface functioning and immediate management requirements. Subsurface evaluation indicates the net result of long-term management.

Visual evaluation of soil structure generates a summarizing structural quality (Sq) score between 1 (optimal) and 5 (poor) (Ball *et al.*, 2007; Guimarães *et al.*, 2011), typically defined in terms of arable soil management. Sq 4 was the highest score from an Irish grassland survey (Cui *et al.*, 2014), while Ball *et al.* (2017) reported Sq 4.2 associated with imposed livestock and machinery compaction in Scotland. This suggests the damage represented by Sq 5 for arable soils is not necessarily relevant for temperate maritime grassland. Furthermore, the interpretation of Sq 4 and 5 is the same, requiring immediate management change to improve soil structural quality (Ball *et al.*, 2007), potentially making Sq 5 redundant for grasslands.

Despite these limitations, VESS has worked well for grassland. Newell-Price *et al.* (2013) found the Peerlkamp method related to bulk density, while VESS scores related to bulk density, total carbon, nitrogen (Cui *et al.*, 2014) and microbial activity (Cui & Holden, 2015). VESS has been successfully used to identify structural degradation from cattle trampling and potential for nitrous oxide (N₂O) fluxes (Ball *et al.*, 2017). VESS scores corresponded to eleven grassland soil quality indicators including aggregate size distribution, bulk density (ρ_b) and potassium (Askari & Holden, 2014). Therefore, VESS is a solid foundation to

build a VSE technique for grassland. A version of VESS was developed for grasslands as part of the 'Healthy Grassland Soils' project (AHDB, 2014), but does not specifically consider the root-mat and has not appeared in the peer-reviewed literature. Concern about compaction of grasslands in Europe (Bilotta *et al.*, 2007; Creamer *et al.*, 2010; Newell-Price *et al.*, 2013) means that understanding the implications of root-mat damage, poaching and pugging is important for soil management. A VSE method to specifically identify and assess anthropogenic influences on grassland soil structural quality would aid best-practice farm management.

The aim of this work was to develop GrassVESS, designed specifically for structural quality evaluation of pasture soils incorporating a root-mat assessment. The method needed to be quick and easy to deploy by a range of users with minimal training to provide real-time management support. The objectives were then to evaluate GrassVESS by (i) an operator focus group to examine usability and reproducibility given a small amount of training and (ii) comparison with VESS and quantitative indicators of structural quality in a grassland survey.

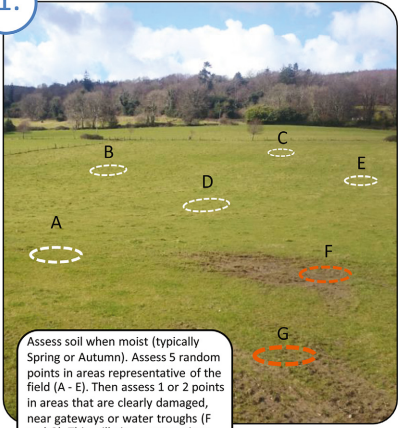
Materials and Methods


The development of GrassVESS


GrassVESS uses the diagnostic properties and scoring of VESS (Ball *et al.*, 2007; Guimarães *et al.*, 2011). VESS requires an intact block of topsoil to ≈ 25 cm depth to be extracted by spade, examined and evaluated for visible layers. Each layer is manually broken up, and aggregate size and shape, porosity, rupture resistance and rooting are compared with a score sheet to decide an Sq score, which are combined for a sample score. GrassVESS (Figures 1 and 2) uses a separate classification procedure for the root-mat and an illustrated flow chart for the lower portion of the sample block. Sq 4 is the highest score possible. The flow chart progresses through soil properties to arrive at a score. Other modifications of VESS are Sq 2 aggregates that can be subangular; in Sq 4, all roots need not be restricted to macro-pores; and the aggregate size threshold was reduced from >10 cm to >7 cm (Guimarães—personal communication). A record sheet (Figure 3) was also developed.


An initial access pit, deeper and wider (≈ 25 cm wide \times 25 cm deep) than the sample block, is required to extract an intact sample block (≈ 15 cm wide \times 15 cm thick \times 20 cm deep). The sample block is placed on a plastic tray or sheet and split open to reveal the root-mat and lower portion, using a knife to cut roots if necessary. Where no distinct root-mat is evident, the upper 6 cm is assessed as such. The lower portion is assessed first, followed by the root-mat generating separate Sq and root-mat (Rm) scores.


How to conduct GrassVESS

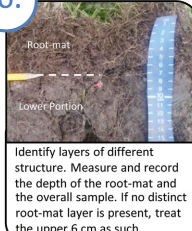
1. 

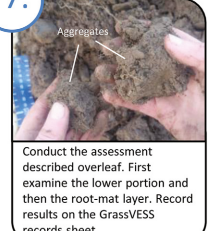
Assess soil when moist (typically Spring or Autumn). Assess 5 random points in areas representative of the field (A - E). Then assess 1 or 2 points in areas that are clearly damaged, near gateways or water troughs (F and G). This will give a comparison between undamaged and damaged areas. At each point, an intact sample block of soil is extracted by spade.
2. 

Dig a hole, wider and deeper than an intended sample block. Do not stand on or lean the spade against the sample block.
3. 

Mark out and carefully loosen the sample block with straight spade insertions.
4. 

Carefully lever out the sample block on the spade and place on a plastic sheet or tray.
5. 

Using a knife or trowel, open the sample block like a book. It is useful to use the spade to gently pull the sample apart.
6. 

Identify layers of different structure. Measure and record the depth of the root-mat and the overall sample. If no distinct root-mat layer is present, treat the upper 6 cm as such.
7. 

Conduct the assessment described overleaf. First examine the lower portion and then the root-mat layer. Record results on the GrassVESS records sheet.

Results

Structural quality (*Sq*) and Root-mat (*Rm*) scores indicate the impact of land management on soil structure at different soil depths. This can help in making management decisions. Low scores indicate that land management is not negatively impacting soil structure. High scores indicate that management is negatively impacting soil structure and changes in management may be necessary.

Lower Portion (*Sq*) Score

- Sq 1 Optimal Structure**
No change in management necessary. Aim to maintain this soil structure condition.
- Sq 2 Good Structure**
Generally, no change in management necessary. However, if Sq 1 was obtained in a previous assessment, some minor changes in management may be required.
- Sq 3 Moderate Structure**
Changes in management necessary. Avoid livestock and machinery traffic in wet conditions and allow the soil to recover naturally.
- Sq 4 Poor Structure**
Changes in management necessary. Seek advice as interventions such as ploughing and reseeded may be required.

Root-mat Layer (*Rm*) Score

- Rm 1 Optimal Structure**
Management is not impacting the root-mat. Aim to maintain this soil structure condition.
- Rm 2 Moderate Structure**
Management is starting to negatively impact the root-mat. Avoid livestock and machinery traffic in wet conditions and allow the soil to recover naturally.
- Rm 3 Poor Structure**
Management is negatively impacting the root-mat. Seek advice. Depending on the depth of the root-mat layer and the condition of the lower portion, either allowing natural recovery or interventions such as ploughing and reseeded may be required.

J.P. Emmet-Booth, O. Fenton, P.D. Forristal, G. Bondi, R.E. Creamer, E. Jeuken & N.M. Holden. 2017. GrassVESS is based on the Visual Evaluation of Soil Structure (VESS) Method developed by B.C. Ball, R.M.L. Guimarães, T. Batey & L.J.

Figure 1 GrassVESS front page (intended for production on A3 size paper) giving instructions on procedure deployment and result explanations.

The evaluation of GrassVESS

The method was evaluated by a focus group to assess ease of deployment and reproducibility and a grassland survey (trained operator) to test for contrasting soils and conditions.

The focus group, conducted at the UCD Lyons Research Farm, Co. Kildare, Ireland (53.299200 N, -6.536339 W), in April 2017, consisted of seven graduate students with varying knowledge of soil, given 60 min training and a field demonstration. In a single grazed paddock, with a silty, silty clay loam (Collins & Brickley, 1970) at an approximate soil moisture deficit (SMD) of 37 mm (Met Éireann, 2017), each member of the group used VESS and GrassVESS in a 50 m² area. No background history about the methods was provided. After deploying both methods, a scored questionnaire was completed about ease of deployment, how

each method dealt with technical information, navigation of the score sheet and the assessment of the root-mat. Arithmetic mean scores were calculated, and qualitative responses were used to interpret the meaning.

The grassland survey was conducted across Ireland (Figure 4) from April to June and September to October 2015. Sites represented a range of agro-climatic regions (Holden & Brereton, 2004) and soils classified as poorly drained surface water gleys (Stagnosols) ($n = 10$) or well-drained brown earths (Cambisols) ($n = 20$) (Creamer *et al.*, 2014). Particle size distribution was measured by pipette (British Standards Institution, 1989) from bulk samples taken from the upper horizon of each site (Table 1). Management intensity was determined using the framework of Cui *et al.* (2014): farm stocking rate (Livestock Units (LU)/ha), time since last reseeded (years) and inorganic nitrogen (kg N/ha/yr) (Table 4). The score for each attribute

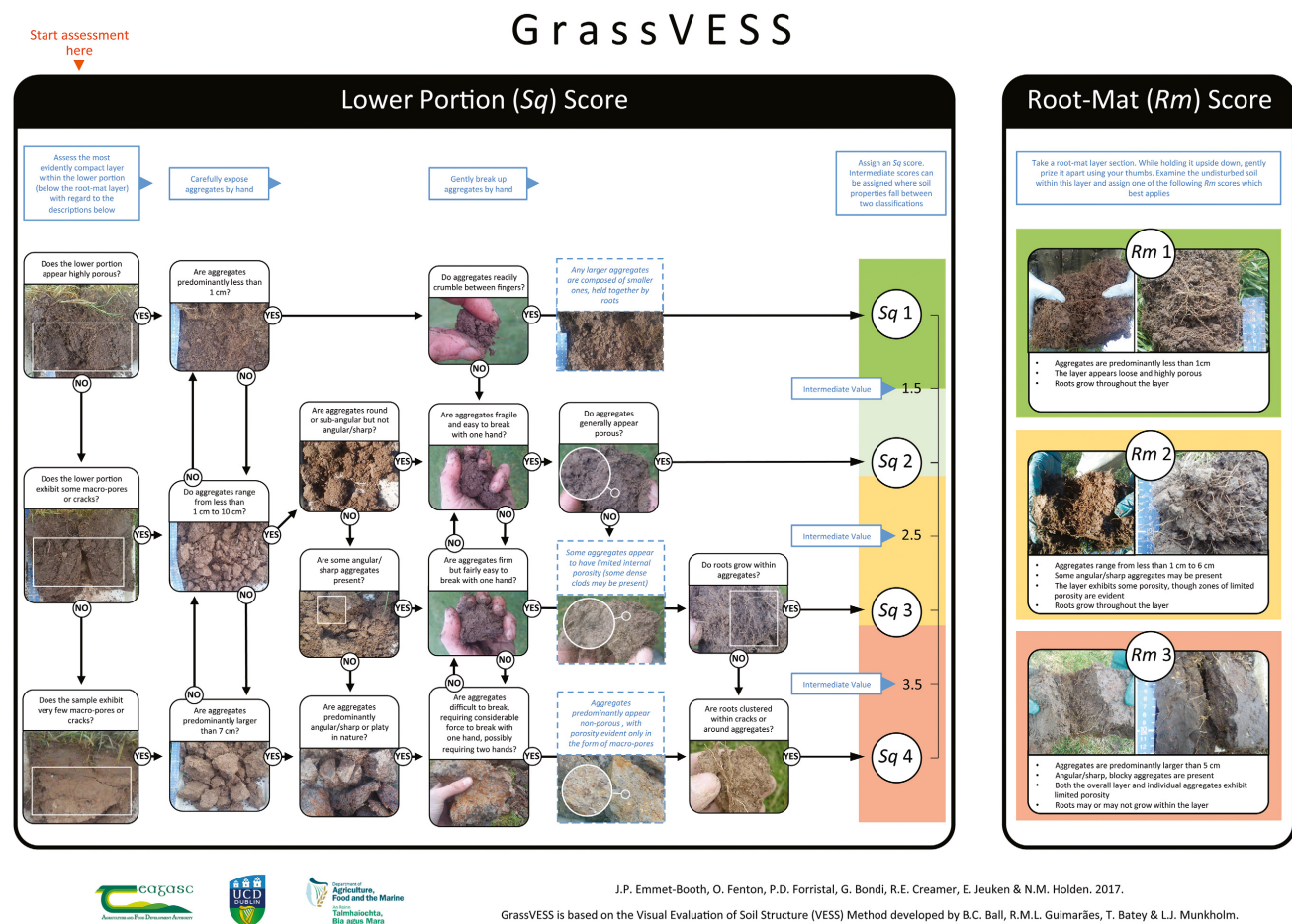


Figure 2 GrassVESS back page (intended for production on A3 size paper) outlining the ‘lower portion’ classification flow chart and ‘root-mat’ classification system.

was plotted on x -, y - and z -axes with the resulting position along the cubic diagonal used to calculate an integer intensity score of 1–5.

At each site, a 30 m² area was marked in a typical field area within which three sample points were located. A sampling point was also located in an atypical area near a water tough or gateway. At each point, VESS, GrassVESS, quantitative indicators of soil structure and pugging scores (Nie *et al.*, 2001) were obtained. The latter involved the visual estimation of exposed soil (damaged sward) area within a 1-m quadrat, generating scores between 1 and 5, where 5 indicated 100% exposure. The quantitative indicators were surface roughness using the chain reduction (Saleh, 1994) calculated from six measurements, with a 1-m bicycle chain laid over the soil surface along a metre stick and the resulting chain length recorded. ρ_b , total- (ϵ) and macro-porosity (ϵ_{mac}) were determined from 2 × Ø 5 cm × h 5 cm intact cores at 5–10 cm and 10–20 cm depth. The latter were treated according to Flint & Flint (2002) and Piowarczyk *et al.* (2011) where sample bases were covered with open cloth (1 mm) secured with steel clips. Samples were saturated by placing on racks held within sealable containers into which water was added to

≤1 mm of sample surfaces and left for 64 h. Samples were then allowed to drain by gravity on racks within empty sealed containers, maintained at 4 °C in a dark room, for 24 h at which point macro-pores were considered to have drained. Although this method does not reflect the boundary conditions in the field for free drainage after saturation and the value of macro-porosity will tend to be underestimated, it still allows for adequate assessment of the different structural conditions. Finally, samples were dried at 105 °C for 44 h. Sample mass was determined at each stage, allowing calculation of ρ_b , volumetric water content (θ) and therefore the estimation of ϵ and ϵ_{mac} .

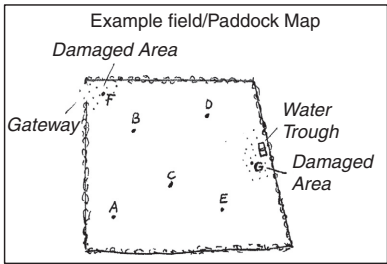
Arithmetic mean values for each property (VESS, GrassVESS, pugging score, chain reduction, ρ_b , ϵ , ϵ_{mac}) were calculated using the three sampling points as replicates per site. As GrassVESS does not generate a summarizing score, VESS Layer 1 (L1) and Layer 2 (L2) scores were compared with GrassVESS Rm and lower portion (LP) scores. Where three VESS structural layers were observed, scores for Layers 2 and 3 were combined. For both VESS and GrassVESS, Sq scores of ≤2 were classified as good structural quality, >2 to ≤3 as moderate and >3 as poor (Ball

GrassVESS Record Sheet	Date:	Field/Paddock Name:	Code:
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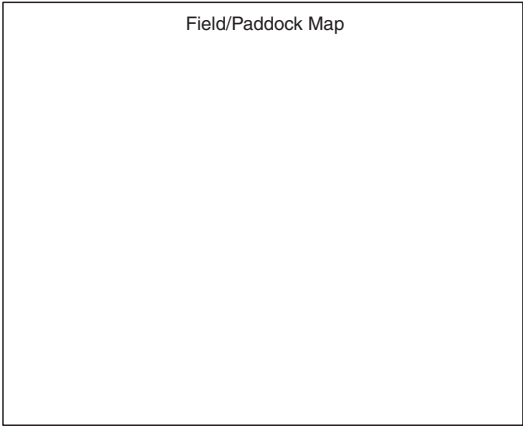
Draw a map of the field/paddock being examined and mark roughly where each assessment (A to G) takes place. Label the assessments as in the example provided below. Assessments conducted in representative areas are marked A to E and in damaged areas, F and G.

For each assessment, mark the depth of the root-mat layer and the overall sample. Record the *Sq* and the *Rm* scores as in the example provided

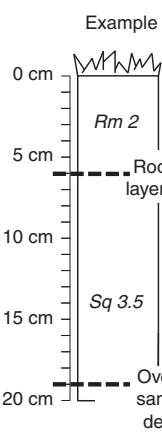
Example field/Paddock Map



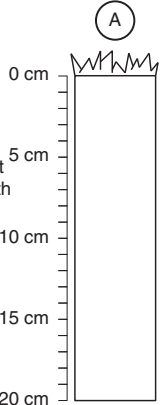
Field/Paddock Map



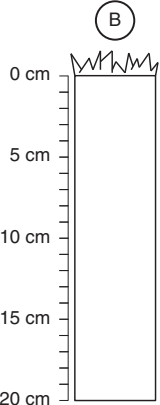
Example



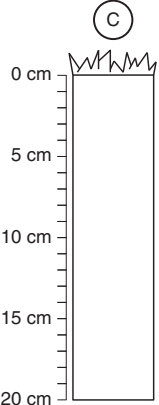
(A)



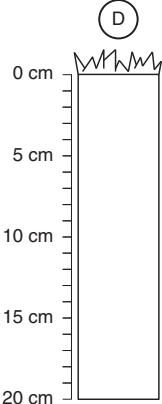
(B)



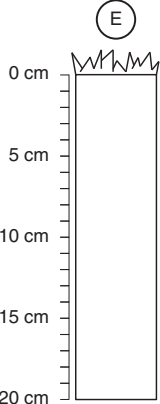
(C)



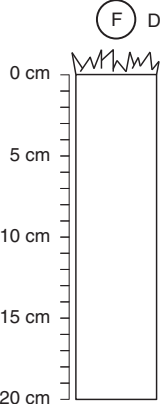
(D)



(E)



(F) Damaged Areas



(G)

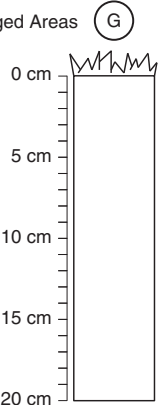


Figure 3 GrassVESS record sheet, designed to clearly illustrate results, using an approach devised by Guimarães *et al.* (2013).

et al., 2007). *Rm* scores of 1, 2 and 3 were classified as good, moderate and poor respectively with site mean values rounded to nearest whole numbers.

All statistical analysis was conducted using R Studio 3.1.1 (R Core Team, 2014) with nonparametric (Wilcoxon signed-rank, Mann–Whitney *U*, Spearman's rank, Kruskal–Wallis) tests. For management intensity, mean measurement values for each intensity class were determined and trends visually identified.

Results

Operator focus group

Most (6 of 7) of the focus group had some experience of soil, ranging from desk research to laboratory analysis. None were familiar with VSE. Both procedures resulted in similar scores for below root-mat structure (*Sq* 2.5); however, surface layer evaluation differed (Table 2; VESS L1

Sq = 2.7, GrassVESS *Rm* = 1.9). VESS resulted in a greater range of scores and scored slightly worse for ease of deployment (Table 2; VESS = 2.7, GrassVESS = 2.1). Operators suggested that VESS was more detailed, but the concurrent assessment of properties was difficult in practice. GrassVESS was described as complex, although the flow chart aided score determination. The presentation of technical information (e.g. aggregation, sizes, strengths) was easier to follow for GrassVESS (Table 2; VESS = 2.7, GrassVESS = 1.6), with the images for each decision highlighted as beneficial. Methods were similarly ranked for ease of using the score sheets (Table 2; VESS = 3, GrassVESS = 2.9). Operators noted that VESS facilitated independent assessment of each property without considering previous diagnoses, yet classification was described as too rigid. GrassVESS required the continuous reconsideration of previous decisions, but the decision structure was easier to follow. The root-mat evaluation was more difficult by VESS (Table 2; VESS = 4, GrassVESS 1.4) with diagnostic

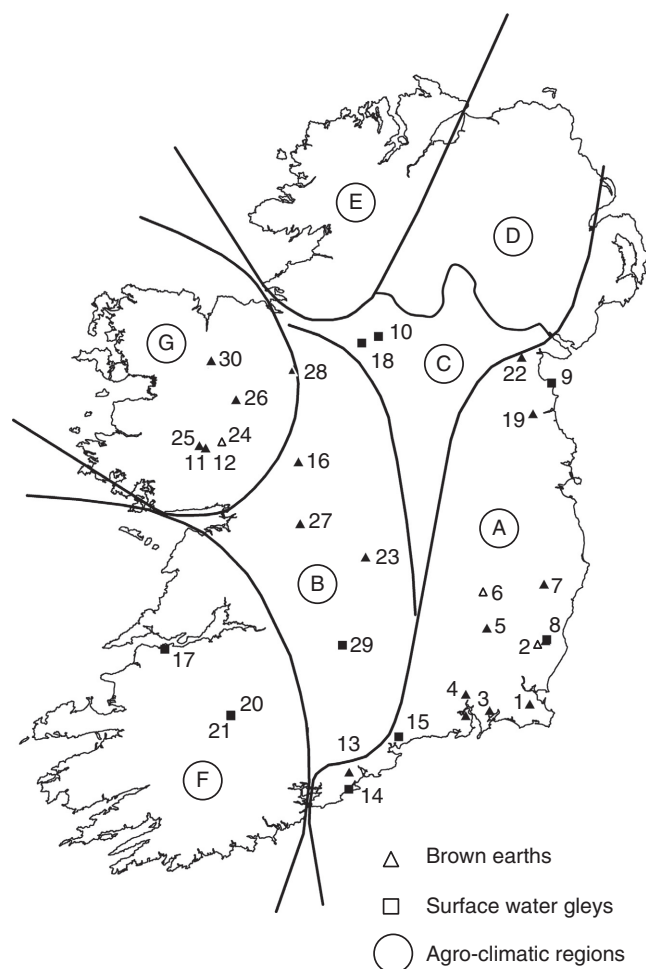


Figure 4 Survey sites across agro-climatic regions of Ireland according to Holden & Brereton (2004).

descriptions indicated as not being related to the root-mat, and GrassVESS described as better. For most operators (5 of 7), GrassVESS was quicker (Table 2), while 4 of 7 indicated that they would be more inclined to use GrassVESS (Table 2) reasons given related to the images to support decisions and clear directions.

Field survey

During sampling, θ (10–20 cm depth) ranged from 0.22 to 0.56 g/cm³ with the SMD outlined for each site (Table 1). Both VSE methods for all soil layers indicated that soil structural quality was poorer in atypical areas, a finding supported by pugging scores and all quantitative measurements including chain reduction, ρ_b , ε and ε_{mac} (Table 3). Root-mat depth was significantly greater in typical areas (mean of 5.7 cm), and in atypical areas, GrassVESS indicated greater root-mat damage than VESS for the surface layer. Rm scores classified 18% more of the atypical

Table 1 Soil texture data and predicted soil moisture deficit at time of sampling for field survey sites

Site	Sand (%)	Silt (%)	Clay (%)	SMD ^a (mm)
01	26.4	47.6	26	29
02	41.8	39.2	19	25
03	43.3	31.7	25	3
04	34.9	40.1	25	9
05	33.9	40.1	26	10
06	68.2	16.8	15	11
07	30.3	45.7	24	11
08	33.8	39.2	27	5
09	26.6	36.4	37	27
10	46.7	37.3	16	9
11	42.3	31.7	26	3
12	44.2	30.8	25	5
13	46.4	33.6	20	18
14	46.1	28.9	25	22
15	40.0	42.0	18	22
16	54.1	28.9	17	32
17	26.0	42.0	32	30
18	43.1	28.9	28	8
19	34.9	40.1	25	–10
20	22.6	50.4	27	4
21	26.6	49.5	24	6
22	35.6	35.5	29	12
23	45.3	31.7	23	9
24	42.6	36.4	21	1
25	43.1	28.9	28	1
26	49.6	35.5	15	3
27	31.1	42.9	26	6
28	45.2	30.8	24	5
29	12.6	49.5	38	10
30	58.6	22.4	19	0

^aSMD = Soil Moisture Deficit as predicted by Met Éireann (2017).

areas as severely damaged compared with VESS L1 Sq scores ($n = 28$). VESS Sq scores slightly better correlated with pugging scores ($r_s = 0.52$, sig = 0.007) than GrassVESS Rm scores ($r_s = 0.49$, sig = 0.01) for atypical areas. VESS L2 and GrassVESS LP Sq scores were significantly correlated ($r_s = 0.73$, $P = < 0.01$) with 71% of atypical areas classified as poor structural quality by both ($n = 28$). For typical areas, neither VESS L1 Sq ($U = 58.5$, sig = 0.07) nor GrassVESS Rm ($U = 70.5$, sig = 0.17) scores showed significant difference by soil type. A significant difference was observed for VESS L2 ($U = 26.5$, sig = 0.001) and GrassVESS LP ($U = 31.5$, sig = 0.003) by soil type. VESS classified 30% of brown earth soils as having poor structure below the root-mat structure, but GrassVESS classified 40% as poor structure, while both classified 80% of surface water gleys as having poor below root-mat structure.

Considering all field areas, significant ($P = < 0.01$) correlations were found between VESS L1 Sq and GrassVESS Rm scores ($r_s = 0.89$) and VESS L 2 and

Table 2 Focus group questionnaire responses

Operator	Presentation												Inclined usage	
	Ease of deployment (1 = easy, 5 = difficult)				of technical information (1 = well, 5 = poor)		Score sheet navigation (1 = easy, 5 = difficult)		Ease of root-mat evaluation (1 = easy, 5 = difficult)		Time requirement (Minutes)			
	VESS	VESS	GrassVESS	GrassVESSLP	VESS	GrassVESS	VESS	GrassVESS	VESS	GrassVESS	VESS	GrassVESS		
	L1 Sq	L2 Sq	Rm	Sq	VESS	GrassVESS	VESS	GrassVESS	VESS	GrassVESS	VESS	GrassVESS		
01	4	3	2	3	2	3	2	2	4	4	2	10	7	Both equally
02	3	2	2	3	4	2	2	5	2	5	1	13	11	GrassVESS
03	2	1.5	2	2	2	3	3	3	2	3	1	9	15	VESS
04	2	2	1	2.5	2	3	3	1	3	3	2	15	35	Both equally
05	1	2	1	2	3	1	4	3	4	4	1	23	10	GrassVESS
06	–	4	2	3	3	2	3	4	2	5	2	21	8	GrassVESS
07	4	3	3	2	3	1	2	3	3	4	1	6	5	GrassVESS
Mean	2.65	2.50	1.86	2.50	2.7	2.1	2.7	1.6	3	2.9	4	13.9	13	
Range	3	2.5	2	1	2	2	2	1	4	2	2	17	30	

GrassVESS LP Sq scores ($r_s = 0.87$). Although both significantly ($P = < 0.01$) correlated with pugging scores, GrassVESS Rm scores demonstrated a stronger relationship ($r_s = 0.52$) than VESS Sq scores ($r_s = 0.48$). No correlation was observed between pugging scores and below root-mat structure scores. For typical field areas, VESS and GrassVESS indicated similar structural conditions. VESS classified 80% of sites with no surface damage and 20% with moderate surface damage. GrassVESS classified 70% with no root-mat damage and 30% with moderate root-mat damage ($n = 30$). Regarding the below root-mat soil, VESS classified 47% and GrassVESS 53% with poor structure.

Relationship with quantitative indicators and management

ρ_b 5–10 cm, ε_{5-10} cm and chain reduction showed significant differences between typical and atypical areas (Table 3). There was a significant difference in ρ_b 5–10 cm and ε_{5-10} cm based on VESS L1 ($H = 10.48$, $df = 2$, $sig = 0.005$; $H = 12.32$, $df = 2$, $sig = 0.002$) and GrassVESS Rm ($H = 12.38$, $df = 2$, $sig = 0.002$; $H = 14.26$, $df = 2$, $sig = 0.0007$) classification, with better correspondence with GrassVESS (Figure 5). There were significant differences in ε_{mac} 5–10 cm and ε_{mac} 10–20 cm based on VESS L2 ($H = 8.77$, $df = 2$, $sig = 0.012$; $H = 9.69$, $df = 2$, $sig = 0.008$) and GrassVESS LP ($H = 12.03$, $df = 2$, $sig = 0.002$; $H = 13.07$, $df = 2$, $sig = 0.001$) classification. Significant difference in chain reduction according to VESS L1 ($H = 7.58$, $df = 2$, $sig = 0.02$) and GrassVESS Rm ($H = 8.44$, $df = 2$, $sig = 0.01$) classification was observed. Chain reduction also differed significantly ($P = < 0.01$) with pugging score ($H = 16.21$, $df = 5$). For typical areas, ε_{mac} significantly differed at both 5–10 cm ($U = 148.5$, $sig = 0.03$) and 10–20 cm ($U = 177.5$, $sig = 0.0007$) per soil group, with surface water gleys associated with 30% less mean ε_{mac} 5–10 cm and 48% less ε_{mac} 10–20 cm.

For typical areas, significant differences in indicators according to management intensity factors are outlined (Table 4) although few were found. Visible trends indicated stocking rate to have a greater impact than N-input and reseeded. VESS L1 and GrassVESS Rm scores both indicated that root-mat structure was negatively affected by increased stocking rate. ρ_b , ε and pugging scores indicated similar trends. VESS L2 and GrassVESS LP Sq scores suggested that at higher stocking rates (classes 2 and 3) structural damage occurred at deeper soil depths. With increasing years since last reseeded, ρ_b 5–10 cm decreased and ε_{mac} 10–20 cm increased. VESS L2 and GrassVESS LP scores suggested structural damage associated with the least time since reseeded (class 3). VESS L1 scores indicated a decline in soil quality with increased overall management intensity, as reflected in ρ_b 5–10 cm and ε_{5-10} cm, but this was not reflected in GrassVESS Rm scores. Both VESS L2 and GrassVESS LP scores indicated a gradual decline in quality

Table 3 Relationship between measurements and field area

Measurement	Field area mean values		Significance of difference (Wilcoxon signed-rank test)
	Typical (n)	Atypical (n)	
VESS L1	Sq 1.59 (30)	Sq 2.36 (28)	$Z = 22.5$, sig = 0.0005**
VESS L2	Sq 3.01 (30)	Sq 3.41 (28)	$Z = 65.5$, sig = 0.009**
GrassVESS RM	Rm 1.31 (30)	Rm 2.11 (28)	$Z = 10$, sig = 0.0001**
GrassVESS LP	Sq 2.98 (30)	Sq 3.32 (28)	$Z = 62.5$, sig = 0.007**
Pugging Score	1 (30)	2 (26)	$Z = 15.5$, sig = 0.0003**
ρ_b 5–10 cm	1.01 g/cm ³ (30)	1.10 g/cm ³ (28)	$Z = 94$, sig = 0.01*
ρ_b 10–20 cm	1.13 g/cm ³ (30)	1.20 g/cm ³ (26)	$Z = 87.5$, sig = 0.08
ε_{5-10} cm	58.03 (30)	55.25 (28)	$Z = 314$, sig = 0.01*
ε_{10-20} cm	53.79 (30)	51.97 (26)	$Z = 226$, sig = 0.20
ε_{mac} 5–10 cm	2.07 (30)	1.96 (28)	$Z = 263.5$, sig = 0.17
ε_{mac} 10–20 cm	2.21 (30)	2.02 (26)	$Z = 187$, sig = 0.78
Chain Reduction	3.74 cm (30)	6.65 cm (28)	$Z = 65$, sig = 0.001**
Root-mat depth	5.73 cm (30)	3.5 cm (28)	$Z = 340$, sig = 0.0003**

**Significant at $P = 0.01$; *Significant at $P = 0.05$.

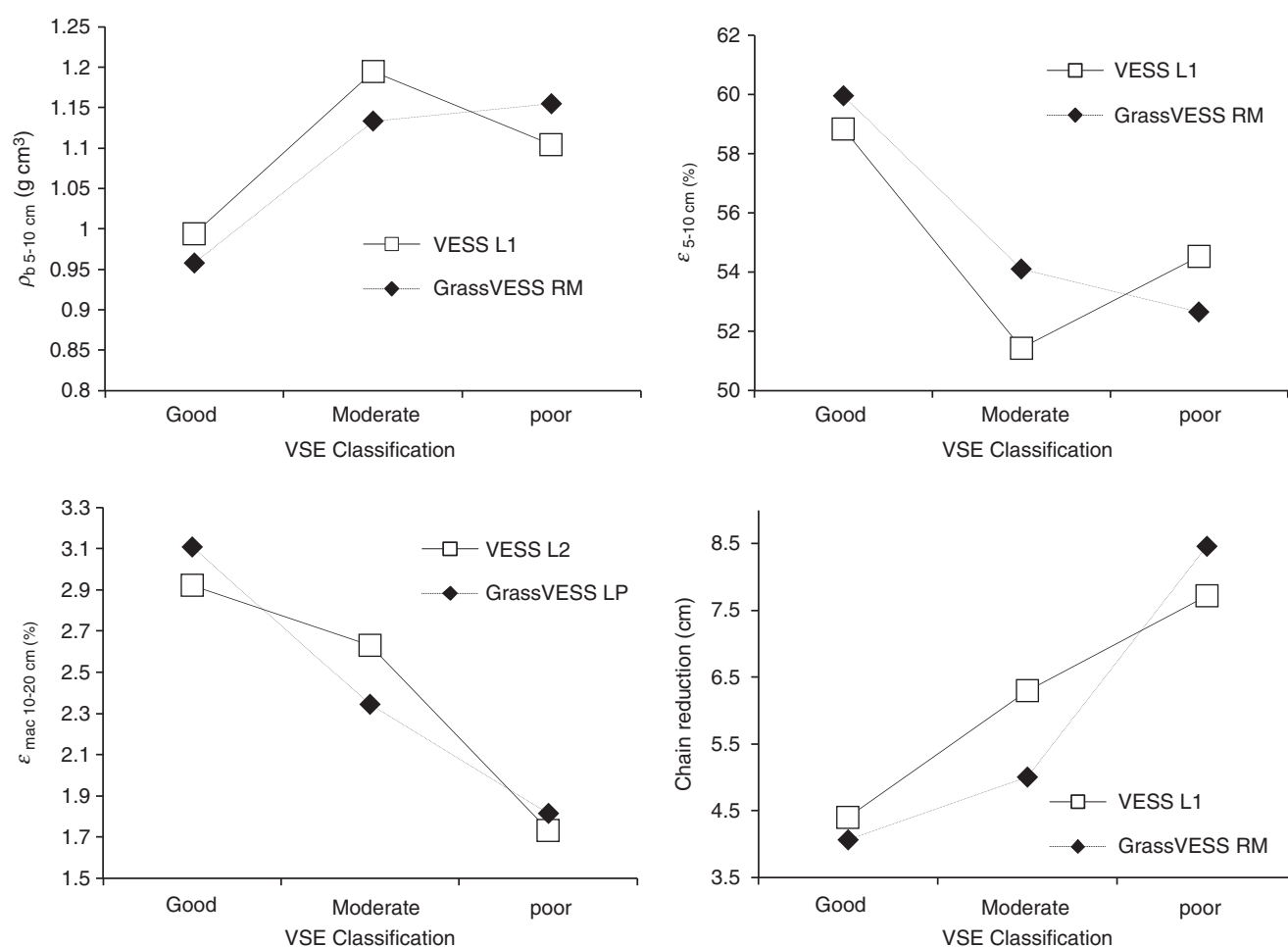
**Figure 5** Mean quantitative indicator values according to VSE structural quality classification.

Table 4 Mean measurement values per management intensity class for typical field areas

Intensity class	VESS L1 (Sq)	VESS L2 (Sq)	Grass VESS Rm (Rm)	Grass VESS LP (Sq)	ρ_b 5–10 cm (g/cm ³)	ρ_b 10–20 cm (g/cm ³)	ε_{5-10} cm (%)	ε_{10-20} cm (%)	ε_{mac} 5–10 cm (%)	ε_{mac} 10–20 cm (%)	Pugging score
Stocking R. (LU/ha)	*a		*b								
1 (<1.5)	1.4	2.7	1.2	2.7	0.96	1.10	59.66	54.92	2.30	2.82	0
2 (1.5–2.5)	1.6	3.1	1.3	3.1	1.00	1.13	58.54	54.18	1.94	1.81	1
3 (≥ 2.5)	2.2	3.3	1.8	3.1	1.13	1.33	52.43	49.74	2.16	2.80	2
Reseeding (years since)											
1 (≥ 20)	1.5	2.9	1.3	2.9	0.96	1.13	59.62	53.59	2.09	2.42	1
2 (10–20)	1.4	2.9	1.8	2.9	0.99	1.10	58.57	55.70	2.35	2.01	2
3 (0–10)	1.9	3.3	1.4	3.2	1.14	1.14	53.39	53.23	1.85	1.76	2
N Input (kg/ha)			*c								
1 (0–43)	1.9	2.5	1.9	2.4	1.03	1.12	58.59	54.25	1.73	2.82	1
2 (43–129)	1.5	2.9	1.2	2.9	0.96	1.11	59.59	54.24	2.03	2.03	0
3 (≥ 129)	1.7	3.2	1.4	3.1	1.07	1.17	55.72	52.51	2.16	2.28	1
Overall Intensity							*d			*e	
2	1.4	2.3	1.3	2.3	0.92	1.08	60.74	54.62	2.29	3.25	1
3	1.5	3.1	1.2	3.1	1.00	1.18	58.92	52.85	1.90	1.50	0
4	1.6	3.2	1.4	3.2	1.02	1.11	57.34	54.53	2.19	2.38	1
5	2	3.4	1.5	3.3	1.18	1.24	51.35	49.61	1.76	1.61	1

*Significant at $P = 0.05$. ^a $H = 6.2135$, $df = 2$, $sig = 0.045$; ^b $H = 6.8128$, $df = 2$, $sig = 0.033$; ^c $H = 6.8943$, $df = 2$, $sig = 0.032$; ^d $H = 8.0827$, $df = 3$, $sig = 0.044$; ^e $H = 9.1279$, $df = 3$, $sig = 0.028$.

with overall management intensity, not reflected in quantitative measurements taken at 10–20 cm depth.

Discussion

The aim of this work was to develop a VSE method specifically for grassland appropriate for a range of users and real-time soil management support. The most important requirement was to properly address the contrasting structure and temporal morphology of the root-mat and lower layers. This was achieved by separating the descriptions for each layer. The identification and assessment of separate layers when using VSE have been widely advocated (Giarola *et al.*, 2010; Guimarães *et al.*, 2011; Cherubin *et al.*, 2017), notably in grassland (Newell-Price *et al.*, 2013; Ball *et al.*, 2017) because understanding the position of compacted layers aids management (Guimarães *et al.*, 2013; Ball *et al.*, 2017). A previous survey of Irish grasslands (Cui *et al.*, 2014) and this survey show that root-mats are typical of temperate grasslands, as also reported for tropical pastures (Cherubin *et al.*, 2017; Guimarães *et al.*, 2017). Root-mats appear only absent with severe stress, and when missing, GrassVESS treats the upper 6 cm of soil as a 'root-mat zone', indicative of severe damage. GrassVESS addresses the typical structure of pasture soils found in many parts of the world, and because it is based on VESS, which has been used globally (e.g. Munkholm *et al.*, 2013; Pulido Moncada *et al.*, 2014; Guimarães *et al.*, 2017), GrassVESS is potentially usable for any grassland soil.

Further testing of the detail of GrassVESS in other regions is a critical next step in its development.

The focus group indicated that GrassVESS greatly aided assessment compared with VESS. The flow chart was designed to rapidly find the correct classification starting from inter-aggregate porosity, following Shepherd (2009). The use of questions with only two answers at each decision point helps the operator to then focus on one property at a time. It is potentially difficult to specify each question to be universal for all users, so further global testing is required. The inclusion of images is beneficial to ease engagement with technical detail for a range of users. For inexperienced or infrequent operators, the flow chart approach of GrassVESS may make it be more suitable than VESS. The focus group responses supported the design, indicating that some users are happy with the flexibility of the VESS, most preferred the structure of GrassVESS. The flow chart might be more complex, but reduces uncertainty as indicated by the lower variation of scores with GrassVESS.

The field survey indicated that VESS and GrassVESS can lead to similar conclusions. Both techniques identified poorer structural quality in atypical areas, although not significantly reflected in all quantitative measurements. Both methods might underestimate structural quality in grasslands, but given the body of evidence associated with VESS (e.g. Guimarães *et al.*, 2013; Munkholm *et al.*, 2013; Askari *et al.*, 2015), it is more likely that the quantitative measurements do not reflect the integration of attributes inherent in VSE. The strong relationship between VESS L2 and GrassVESS LP was achieved because the flow chart went through many

iterations before deployment to ensure a similar result was obtained. The VESS L1 and GrassVESS Rm results were different, with GrassVESS Rm better correlated with pugging. VESS L1 indicated a gradual decline in quality with management intensity not reflected by GrassVESS Rm. However, $\rho_{b\ 5-10\text{ cm}}$ and $\varepsilon_{5-10\text{ cm}}$, both indicators of interface, function better related to GrassVESS Rm, suggesting the system may be more suitable for predicting soil functioning.

Shepherd (2009) and Ball *et al.* (2017) suggested that VSE can be used to identify conditions that enhance N₂O fluxes and surface run-off. Using Rm scores for early warning of subsurface compaction, nutrient use inefficiency and environmental degradation warrants research. For example, fertilizer or slurry application may be inappropriate on areas classified as Rm 3, associated with lower porosity (Figure 5), higher pugging scores (less vegetative cover) and theoretically poor infiltration and aeration, thus potentially encouraging run-off and denitrification (Alderfer & Robinson, 1947; Ball, 2013; Ball *et al.*, 2017).

Conclusion

GrassVESS was specifically developed for the evaluation of temperate maritime managed grasslands and may be suitable for use in other regions with grazed pastures. GrassVESS was found to be quick, straightforward and reproducible, more so than VESS. This was related to the specific root-mat evaluation system and the decision structure with supporting images used to direct the operator through the scoring decisions. Less variation between operators and greater certainty when scoring should be achieved. Therefore, GrassVESS can be used by a range of users on an ongoing basis to aid real-time grassland soil management.

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References

- AHDB. 2014. Healthy Grassland Soils – four quick steps to assess soil structure. Agriculture and Horticulture Development Board. United Kingdom. Available at: <http://beefandlamb.ahdb.org.uk/grazing-club/assess-soil-structure/>; accessed 25/08/2016.
- Alderfer, R.B. & Robinson, R.R. 1947. Runoff from pastures in relation to grazing intensity and soil compaction. *Journal of the American Society of Agronomy*, **39**, 948–958.
- Askari, M.S. & Holden, N.M. 2014. Indices for quantitative evaluation of soil quality under grassland management. *Geoderma*, **230–231**, 131–142.
- Askari, M.S., Cui, J., O'Rourke, S.M. & Holden, N.M. 2015. Evaluating soil structural quality using VIS-NIR spectrum. *Soil & Tillage Research*, **146** Part A, 108–117.
- Ball, B.C. 2013. Soil structure and greenhouse gas emissions: a synthesis of 20 years of experimentation. *European Journal of Soil Science*, **64**, 357–373.
- Ball, B.C., Batey, T. & Munkholm, L.J. 2007. Field assessment of soil structural quality – a development of the Peerlkamp test. *Soil Use and Management*, **23**, 329–337.
- Ball, B.C., Cameron, K.C., M., Di, H.J. & Moore, S. 2012. Effects of trampling of a wet dairy pasture soil on soil porosity and on mitigation of nitrous oxide emissions by a nitrification inhibitor, dicyandiamide. *Soil Use and Management*, **28**, 194–201.
- Ball, B.C., Munkholm, L.J. & Batey, T. 2013. Applications of visual soil evaluations. *Soil & Tillage Research*, **127**, 1–2.
- Ball, B.C., Guimarães, R.M.L., Cloy, J.M., Hargreaves, P.R., Shepherd, G.T. & McKenzie, B.M. 2017. Visual soil evaluation: a summary of some applications and potential developments for agriculture. *Soil & Tillage Research*, **173**, 114–124.
- Batey, T. 2009. Soil compaction and soil management – a review. *Soil Use and Management*, **25**, 335–345.
- Batey, T. & Killham, K. 1986. Field evidence on nitrogen losses by denitrification. *Soil Use and Management*, **2**, 83–86.
- Bilotta, G.S., Brazier, R.E. & Haygarth, P.M. 2007. The impacts of grazing animals on the quality of soils, vegetation and surface waters in intensively managed grasslands. *Advances in Agronomy*, **94**, 237–280.
- British Standards Institution. 1989. Pipette method (BS 1796, 1989). British standard methods of test for soil for civil engineering purposes. British Standards Institution.
- Cherubin, M.R., Franco, A.L.C., Guimarães, R.M.L., Tormena, C., Cerri, C.E.P., Karlen, D.L. & Cerri, C.C. 2017. Assessing soil structural quality under Brazilian sugarcane expansion areas using visual evaluation of Soil Structure (VESS). *Soil & Tillage Research*, **173**, 64–74.
- Collins, J.F. & Brickley, W.D. 1970. *Soils of Lyons Estate Celbridge, Co. Kildare, Soil Bulletin No.1*. Soil Science Department, University College Dublin, Belfield, Dublin 4, Ireland.
- Creamer, R.E., Brennan, F., Fenton, O., Healy, M.G., Lalor, S.T.J., Lanigan, G.J., Regan, J.T. & Griffiths, B.S. 2010. Implications of the proposed soil framework directive on agricultural systems in Atlantic North-west Europe – a review. *Soil Use & Management*, **26**, 198–211.
- Creamer, R., Simo, I., Reidy, B., Carvalho, J., Fealy, R., Hallett, S., Jone, R., Holden, A., Holden, N., Hannam, J., Massey, P., Mayer, T., McDonald, E., O'Rourke, S., Sills, P., Truckell, I., Zawadzka, J. & Schulte, R. 2014. Irish soil information synthesis report (2007-S-CD-1-S1). Available at: http://gis.teagasc.ie/soils/downloads/EPA_RR130_PRINT.pdf; accessed 30/05/2017.
- Cui, J. & Holden, N.M. 2015. The relationship between soil microbial activity and microbial biomass, soil structure and grassland management. *Soil & Tillage Research*, **146**, 32–38.
- Cui, J., Askari, M.S. & Holden, H.M. 2014. Visual evaluation of soil structure under grassland management. *Soil Use and Management*, **30**, 129–138.
- Drewry, J.J. 2006. Natural recovery of soil physical properties from treading damage of pastoral soils in New Zealand and Australia: a review. *Agriculture, Ecosystems and Environment*, **114**, 159–169.

- Emmet-Booth, J.P., Forristal, P.D., Fenton, O., Ball, B.C. & Holden, N.M. 2016. A review of visual soil evaluation techniques for soil structure. *Soil Use and Management*, **32**, 623–634.
- Flint, L.E. & Flint, A.L. 2002. Porosity. In: *Methods of soil analysis part 4, physical methods* (eds J.H. Dane & G.C. Topp), pp. 241–254. Soil Science Society of America, Fitchburg, WI.
- Giarola, N.F.B., da Silva, A.P., Tormena, C.A., Ball, B.C. & Rosa, J.A. 2010. Visual soil structure quality assessment on Oxisols under no-tillage system. *Scientia Agricola*, **64**, 479–482.
- Guimarães, R.M.L., Ball, B.C. & Tormena, C.A. 2011. Improvements in the visual evaluation of soil structure. *Soil Use and Management*, **27**, 395–403.
- Guimarães, R.M.L., Ball, B.C., Tormena, C.A., Giarola, N.F.B. & da Silva, A.P. 2013. Relating visual evaluation of soil structure to other physical properties in soils of contrasting texture and management. *Soil & Tillage Research*, **127**, 92–99.
- Guimarães, R.M.L., Neves Junior, A.F., Silva, W.G., Rogers, C.D., Ball, B.C., Montes, C.R. & Pereira, B.F.F. 2017. The merits of the visual evaluation of soil structure method (VESS) for assessing soil physical quality in the remote, undeveloped regions of the Amazon basin. *Soil & Tillage Research*, **173**, 75–82.
- Herbin, T., Hennessy, D., Richards, K.G., Piowarczyk, A., Murphy, J.J. & Holden, N.M. 2011. The effects of dairy cow weight on selected soil physical properties indicative of compaction. *Soil Use and Management*, **27**, 36–44.
- Hillel, D. 1998. *Environmental soil physics*. Academic Press, Cambridge, MA.
- Holden, N.M. & Brereton, A.J. 2004. Definition of agroclimatic regions in Ireland using hydro-thermal and crop yield data. *Agriculture & Forest Meteorology*, **122**, 175–191.
- Houlbrooke, D.J., Paton, R.J., Littlejohn, R.P. & Morton, J.D. 2011. Land use intensification in New-Zealand: effects on soil properties and pasture production. *Journal of Agricultural Science*, **149**, 337–349.
- Kurz, I., O'Reilly, C.D. & Tunney, H. 2006. Impact of cattle on soil physical properties and nutrient concentrations in overland flow from pastures in Ireland. *Agriculture, Ecosystems & Environment*, **113**, 378–390.
- Met Éireann. 2017. Display and download historic data. Available at: <http://www.met.ie/climate-request/>; accessed 20/09/2017.
- Mueller, L., Shepherd, T.G., Schindler, U., Ball, B.C., Munkholm, L.J., Hennings, V., Smolentseva, E., Rukhovic, O., Lukin, S. & Hu, C. 2013. Evaluation of soil structure in the framework of an overall soil quality rating. *Soil & Tillage Research*, **127**, 74–84.
- Munkholm, L.J., Heck, R.J. & Deen, B. 2013. Long-term rotation and tillage effects on soil structure and crop yield. *Soil & Tillage Research*, **127**, 85–91.
- Newell-Price, J.P., Whittingham, M.J., Chambers, B.J. & Peel, S. 2013. Visual soil evaluation in relation to measured soil physical properties in a survey of grassland soil compaction in England and Wales. *Soil & Tillage Research*, **127**, 65–73.
- Nie, Z.N., Ward, G.N. & Michael, A.T. 2001. Impact of pugging by dairy cows on pasture and indicators of pugging damage to pasture soil in soil- western Victoria. *Australian Journal of Agricultural Research*, **52**, 37–43.
- Peerlkamp, P. 1959. A visual method of soil structure evaluation. Meded. v.d. Landsbouwhogeschool en Opzoekingsstations van der Staat te Gent. XXIV No. 24, pp. 216–221.
- Phelan, P., Keogh, B., Casey, I.A., Necpalova, M. & Humphreys, J. 2013. The effects of treading by dairy cows on soil properties and herbage production for three white clover-based grazing systems on a clay loam soil. *Grass and Forage Science*, **68**, 548–563.
- Piowarczyk, A., Giuliani, G. & Holden, N.M. 2011. Can soil moisture deficit be used to forecast when soils are at high risk of drainage owing to grazing animals? *Soil Use and Management*, **27**, 255–263.
- Pulido Moncada, M.P., Gabriels, D., Lobo, D., Rey, J.C. & Cornelis, W.M. 2014. Visual field assessment of soil structural quality in tropical soils. *Soil & Tillage Research*, **139**, 8–18.
- R Core Team. 2014. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. Available at: <http://www.R-project.org/>; accessed 18/07/2016.
- Roger-Estrade, J., Richard, G., Caneill, J., Boizard, H., Defosse, P. & Manichon, H. 2004. Morphological characterisation of soil structure in tilled fields: from diagnosis methods to modelling of structural changes over time. *Soil & Tillage Research*, **79**, 33–49.
- Saleh, A. 1994. Measuring and predicting ridge-orientation effect on soil surface roughness. *Soil Science Society of America Journal*, **58**, 1228–1230.
- Shepherd, T.G. 2009. *Visual soil assessment, Volume 1: Field guide for pastoral grazing and cropping on flat to rolling country*, 2nd edn. Horizons regional council, Palmerston North, New Zealand.