SHADOW TRACKING PROCEDURE APPLIED TO FEEDLOT SHADE STRUCTURES

PROCEDURA DI TRACCIAMENTO DELLE OMBRE APPLICATA ALLE STRUTTURE OMBREGGIANTI PER ANIMALI

CARLO BIBBIANI[(1)], SALVATORE BRUNELLO CONSORTI[(2)]

SUMMARY

In hot climate areas during the hottest hours of the day animals seek the protection of shade to mitigate the impact of the direct solar radiation. Thus the provision of shade can be of great relevance in the cattle management. The location of the shade structures is essential to make their shadow easily accessible by the animals. The shade structure position relatively to feedlot area would ensure that shade is kept within the pen during the afternoon. The form of the shadow depends on the slope of the shade material. The height of the structure affect the rate at which the shadow moves across the ground. General recommendations suggest that cattle should be provided with anywhere from 1.9 to 6.0 m^2 of shade per head; in hot humid climates more open area for ventilation is recommended. Major design parameter for permanent shade structures include orientation and location on feedlot, floor space, height, ventilation, shade material and slope, feeding and water facilities, and waste management system.

The aim of this paper is to set up a shadow tracking procedure to determine the best orientation and location on feedlot of a permanent shade structure. The algorithms depend on astronomical parameters such as latitude, Julian day, and hour angle; on structure parameters such as form, height, and slope of shade material.

Key words: shadow tracking; shade structure; best location on feedlot.

RIASSUNTO

Nelle zone climatiche caratterizzate da caldo intenso, gli animali ricercano zone ombreggiate per mitigare gli effetti della radiazione solare. Per questo motivo, il prevedere degli ombreggiamenti è di particolare importanza nella gestione della mandria. La posizione delle strutture ombreggianti deve essere progettata in modo tale da rendere l'ombra facilmente accessibile e proiettata sul terreno all'interno del recinto nelle ore del pomeriggio.

Le raccomandazioni generali suggeriscono di fornire da 1,9 a 6,0 m^2 di ombra a capo; nei climi caldo-umidi è consigliato di favorire la ventilazione. I più importanti parametri necessari per la progettazione delle strutture ombreggianti fisse includono l'orientamento e la posizione nel recinto, lo spazio pro-capite, l'altezza, la ventilazione, i materiale costruttivi e la

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(1) Dipartimento di Produzioni Animali, Direttore Prof. Paolo Verità.
(2) Dipartimento di Agronomia e Gestione dell'Agro-Ecosistema, Direttore Prof. Sergio Miele.

pendenza della copertura, il posizionamento degli abbeveratoi e della mangiatoia ed infine i sistemi di rimozione dei reflui zootecnici.

Lo scopo di questo lavoro è la determinazione di una procedura per il tracciamento dell'ombra proiettata sul terreno da parte di una qualsiasi struttura, in funzione di parametri astronomici quali la latitudine, il giorno 'Giuliano' corrente nell'anno e l'orario, e geometrici quali la forma, l'altezza e la pendenza della copertura. Con questo strumento la progettazione ed il posizionamento della struttura stessa all'interno del recinto di allevamento potrà essere effettuato nel migliore dei modi.

Parole chiave: tracciamento ombra; strutture ombreggianti; posizionamento nei recinti.

INTRODUCTION

The impact of heat stress is prominent on dairying in hot climate Mediterranean areas. Solar radiation and elevated ambient air temperature are the primary sources of heat gain from the environment. High relative humidity and a lack of air movement worsen the situation. Evaporative cooling with water in the form of fog, mist or sprinkling with natural or forced air movement is an active and effective method for altering the environment (Armstrong et al., 1985-1993; Bucklin et al., 1991; Beede et al., 1987) The provision of shade is classified as a passive method; nevertheless it can be of great relevance in the cattle management (Hahn, 1982, 1985; Wiersma, 1982; Mitlöhner et al., 2001b,c; Muller & Botha, 1997).

In hot climate areas during the hottest hours of the day, animals seek the protection of shade. Two options are available: natural or artificial shade. Regardless of the type of artificial shade structures there are a number of factors to consider with respect to design, maintenance, and initial cost.

Many researchers report good performance of shade structures (Blackshaw & Blackshaw, 1994; Buffington et al., 1983; Valtorta et al., 1996, 1997), but a relationship between shaded area, stocking density, and cattle performance has not been defined in the available literature. General recommendations have been made by researchers: US dairy research suggests that cattle should be provided with anywhere from 1,9 to 6,0 m^2 of shade per head. In drier climates 3,5 to 4,5 m^2 per lactating cow is recommended, whilst in hot humid climates 4,2 to 5,6 m^2 provide more open area for ventilation (Armstrong, 1994). A lot of work should be done to improve cattle comfort and productivity and increase profitability; engineering advice on the design of the shade structure are recommended. Particularly, the shape ratio vs. height, the slope of the shade material, the ability of the structure to shed load and dampen out oscillations caused by wind.

The form of the shadow depends on the slope of the shade material. The height of the structure affect the rate at which the shadow moves across the ground (Lazzarin, 1981; Cimieri & Lazzarin, 1983). Studies have shown that cattle show a preference for higher shade structures, perhaps because they spread a lower radiant heat toward the animals and also provide more cool air for cattle.

The location of the shade structures is essential to make their shadow easily accessible by the animals. This is the primary reason that shade structures are typically erected towards the centre of feedlot pens. As the shaded area moves across the pen during the day, cattle are able to occupy the shadow. Conflict with the placement of the water trough needs to be avoided: it is particularly important that feed and water be located within close proximity, but it is necessary to limit manure accumulation and moisture build up (Anonymous, 2002).

During hot, dry periods, commercial feedlots can experience problems with respect to dust generation after sunset. Researcher have found that especially in the evening hours shade decreased dust-generating behaviours of cattle, namely bulling and agonistic behaviour (Mitlöhner et al., 2001a).

Major design parameter for permanent shade structures include: 1) orientation and location on feedlot, 2) floor space, 3) height, 4) ventilation, 5) roof material and slope, 6) feeding and water facilities, and 7) waste management system.

The aim of this paper is to deal about orientation and location on feedlot of a permanent shade structure.

MATERIALS AND METHODS

The first step to evaluate the shadow area of a permanent shade structure is to calculate the shadow cast onto the ground by a vertical rod depending on time and Julian day.

Some angles must be defined, such as:

ϕ = latitude

ω = hour angle (null at solar midday, positive in the morning, negative in the afternoon, 15° degrees each hour)

δ = declination (at midday for a Julian day "d" in the year, $1 \leq d \leq 365$)

$$\delta = 23.45 * \sin[360 * (284+d)/365] \quad (1)$$

$\cos\omega_{d-s}$ = dawn-sunset hour angle

$$\cos\omega_{d-s} = - tg\,\phi * tg\delta \quad (2)$$

Other geometrical relations between solar beam and rod are needed. Take a relative datum-system i', j', k', with i' oriented to North on an horizontal plane at the location point, j' oriented to West on the same horizontal plane, and k' oriented to zenith (see figure 1).

The position of solar beam respect to the datum-system is expressed by its versor n_r:

$$n_r = (\sin\phi * \cos\delta * \cos\omega - \cos\phi * \sin\delta)\ i' + \cos\delta * \sin\omega\ j' - (\cos f\phi * \cos\delta * \cos\omega + \sin\delta * \sin\phi)\ k' \quad (3)$$

The solar height "α" is the angle created by solar beam passing through the tip of the rod and the horizontal plane, and its sinus is given by:

$$\sin\alpha = \cos\phi * \cos\delta * \cos\omega + \sin\delta * \sin\phi \quad (4)$$

Thus, if the rod height is expressed by "h", the projection of the rod itself on the horizontal plane i'j' is h_{xy}:

$$h_{xy} = h/tg\alpha \quad (5)$$

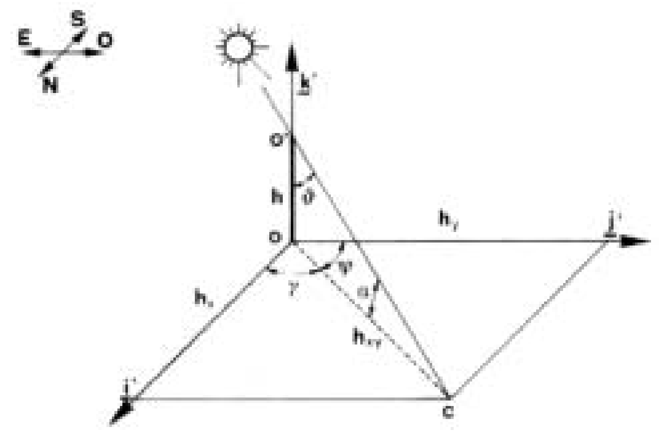

Fig. 1. Geometrical relations between solar beam and rod. Relative datum-system i', j', k', with i' oriented to North on an horizontal plane at the location point, j' oriented to West on the same horizontal plane, and k' oriented to zenith. (From Lazzarin, 1981.)

and its versor is $n_{h(xy)}$:

$n_{h(xy)}$= [(sinϕ*cosδ*cosω – cosϕ*sinδ) i' + cosδ*sinω j']/cosα (6)

The angles formed by this versor with i'j' axis are respectively "γ" and "ψ", given by:

cosγ = (sinϕ*cosδ*cosω – cosϕ*sinδ)/cosα (7)

cosψ = cosδ*sinω/cosα (8)

ψ = oriented-angle, spinning clockwise from West axis

Thus, the projected shade components on i'j' axis are respectively, as Fig. 1 shows:

$h_x = h_{xy}$ cosγ (9)

$h_y = h_{xy}$ cosψ = h_{xy} sinγ (10)

Equation (9) and (10) can be substituted for (4), (7), and (8):

h_x = h * (sinϕ*cosδ*cosω – cosϕ*sinδ)/(cosϕ*cosδ*cosw + sinδ*sinϕ) (11)

h_y = h * cosδ*sinω/(cosϕ*cosδ*cosω + sinδ*sinϕ) (12)

or , in non-dimensional and brief equations:

h_x/h = cosγ/tgα (13)

h_y/h = cosψ/tgα (14)

Now figure out a shade structure characterized by its support poles: at first imagine four of them positioned at the corners of a rectangle.

Denote h_1 and h_3 as the height of couples of support poles in a sloped roof, where h_1=h_2 are the shorter poles and h_3=h_4 are the taller ones. Assume:

r = h_3 / h_1 (15)

L = length of the structure on a longitudinal axis

P = width of the structure

λ = angle of oriented side 1-2, starting from East axis to South, clockwise

Fix pole-1 coordinate as [0;0] and calculate other poles coordinate in non-dimensional form normalizing by h_1.

$pole_{x1}/h_1 = 0;$ $\qquad pole_{y1}/h_1 = 0$ (16)

$pole_{x2}/h_1 = +L/h_1*\cos\lambda;$ $\qquad pole_{y2}/h_1 = -L/h_1*\sin\lambda;$ (17)

$pole_{x3}/h_1 = +L/h_1*\cos\lambda + P/h_1*\sin\lambda;$ $\qquad pole_{y3}/h_1 = -L/h_1*\sin\lambda + P/h_1*\cos\lambda;$ (18)

$pole_{x4}/h_1 = +P/h_1*\sin\lambda;$ $\qquad pole_{y4}/h_1 = +P/h_1*\cos\lambda;$ (19)

Thus, one can plot the shadow projections of support poles $[h_{x1}/h_1;h_{y1}/h_1]$, $[h_{x2}/h_1;h_{y2}/h_1]$, $[h_{x3}/h_1;h_{y3}/h_1]$ and $[h_{x4}/h_1;h_{y4}/h_1]$, by eq. (13) and (14) depending on time 'ω' and on $[\phi;d;h_1;L;P;\lambda]$ parameters.

Finally, the so-called "shadow dawn-angle" 'ψ_d' and "shadow sunset-angle" 'ψ_s' can be determined by:

$$1/tg\psi_{d\text{-}s} = (\cos^2\phi/tg^2\delta - \sin^2\phi)^{0,5} \qquad (20)$$

RESULTS AND DISCUSSION

An Excel® worksheet called "SHADOWTRACK" was made ready to calculate $[h_x/h\ ;h_y/h]$ non-dimensional shadow projection on ground of a shade structure. Any orientation, form or dimension of the structure can be set up.

Figure 2 shows the typical course of the shadow of a vertical rod during summer and winter solstice, and during equinox (ϕ=42° N), plotted by equations (13) and (14). The graphs report a 20 minute-step data: a symmetrical curve comes out, boomerang-shaped, more or less flat, depending on $[\phi;d]$ parameters. Two straight lines, coming out from axis-origin, show the "shadow dawn-angle" 'ψ_d' and "shadow sunset-angle" 'ψ_s'. Their traces are obtained by equation (20). A tracking array can be drawn from axis-origin to determine the direction of the shadow of a rod at a set time.

Figure 3a-b show the shadow courses relatively to support poles $h_1 \div h_4$ during summer solstice (d=172), and the position of the shade structure shadow at 4 pm and at 6 pm (solar time) for an oriented structure (case A: λ=0°; case B: λ=75°; case C: λ=90°; case D: λ=115°).

Orientation of the shade structure must represent a compromise between most effective shading for cattle and maintenance of dry ground surface conditions under the shade. An orientation with the long axis north and south will expose the area under the shade to the morning and afternoon sun and assist in keeping it dry.

Structures with an east-west orientation cause some areas of the feedlot pen to be permanently in shade, which has the advantage of creating cooler pad temperatures.

However, it is important to determine the throw of the shade. Research has found that typically heat stress occurs in the period between 2-6 pm, with cattle often showing most stress in the period between 3-5pm. For this reason, the shadow of the

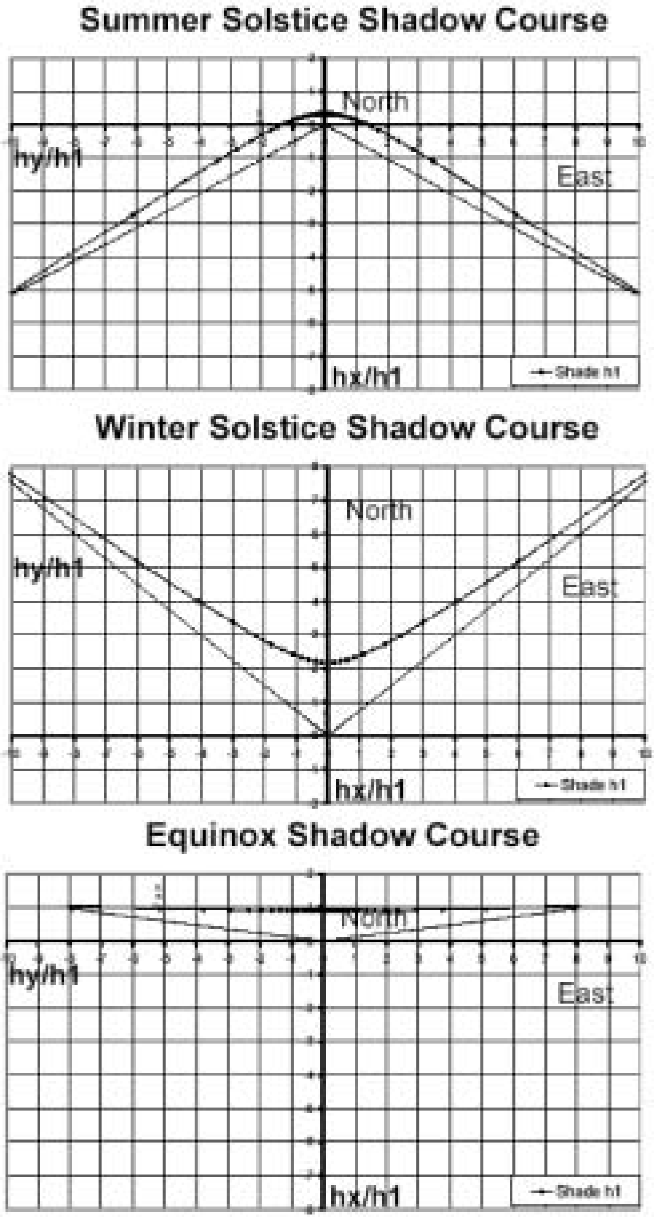

Fig. 2. Typical course of the shadow of a vertical rod during summer and winter solstice, and during equinox [$\phi = 42°$ N; 20 minute-step data]. Two straight lines, coming out from axis-origin, show the “shadow dawn-angle” ‘ψ_d’ and “shadow sunset-angle” ‘ψ_s’

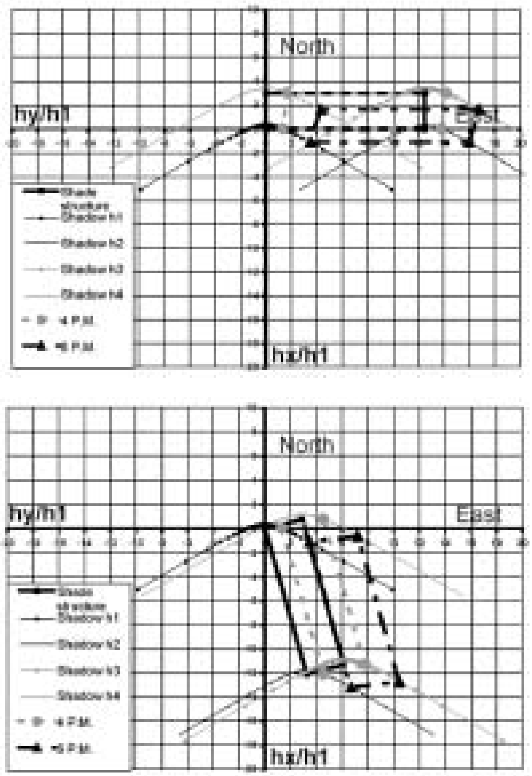

Fig. 3a. Shadow courses relatively to structure poles h1÷h4 during the summer solstice (δ=172); position of the shade structure shadow at 4 p.m. and at 6 p.m. . The dimensioning parameters are: L=50 m; p=12 m; h1=h2=4 m; h3=h4= 5 m; ϕ = 45° N; case A: λ=0°; case B: λ=75°.

shade structure must be kept within the pen during the afternoon. To maximize the afternoon shaded-area it necessary to position the taller structure poles on the north-east side. The shadow tracking procedure allows the determination of the best shade structure location in order to satisfy cattle and shaded area management. Figure 3 shows that during summer afternoon the non-dimensional throw of that shade structure vary from 0.3 to 10. This means that at noon the shadow will overlap the shade structure projection on ground, at 4 pm it will be “1 time” the height of the structure far away, whilst at 6 pm it will be “2÷4 times” the height far away depending on orientation. Finally, at 7 pm (projection not shown) the throw of the shade will cast onto the ground “10 times” the height of the structure, or more, far away. Thus, to ensure a shaded area after 6 pm, feedlots or pens would result in being such wide and properly fenced, as regards to orientation.

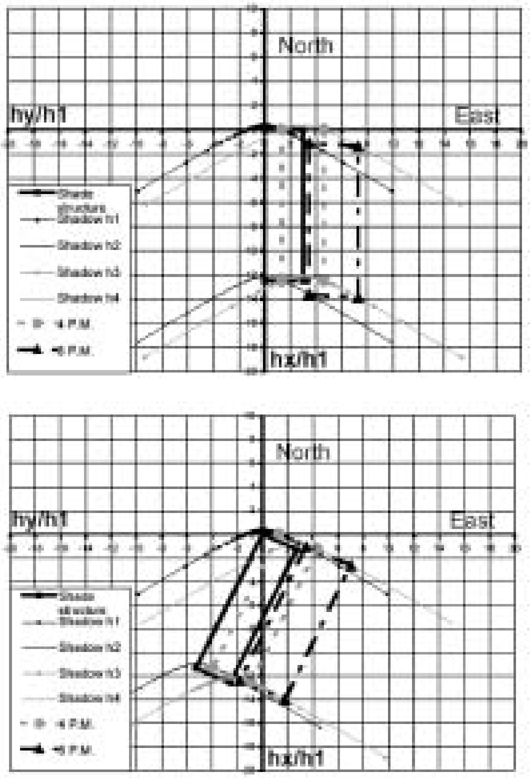

Fig. 3b. Shadow courses relatively to structure poles h1÷h4 during the summer solstice (d=172); position of the shade structure shadow at 4 p.m. and at 6 p.m. . The dimensioning parameters are: L=50 m; p=12 m; h1=h2=4 m; h3=h4= 5 m; f = 45° N; case C: l=90°; case D: l=115°.

CONCLUSIONS

The shadow tracking procedure set up in this study can be applied to any shade structure. Astronomical parameters, as well as orientation, form and dimension of the structure are the design parameters. The procedure results in the evaluation of the shadow area and the rate at which the shadow moves across the ground. Useful consideration can be done with respect to maintenance of dry ground surface conditions under the shade and to location on feedlot.

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