# Effects of water-cooled cover on physiological and production parameters of farrowing sows under hot and humid climates

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**Abstract:** The hot and humid climates, as encountered in the southern region of China with the open housing, can adversely impact the sows undergoing heat stress during the most vulnerable period at lactation. Hence, a water-cooled cover system (WCCs) for local cooling has essential practical value to improve productivity. The WCCs was developed for the sow crate of lactating sows separately, which performance was validated with the cooling efficiency in the sow occupied zone (SOZ) and physiological parameters. The results showed that the WCCs for the farrowing sows using aluminium plastic tubes connected in series could reach an appropriate cooling performance in adjacent units. The WCCs could decrease the SOZ air temperature by 3.0-4.5°C under the extremely hot climate when the indoor air temperature was 37°C, and maintain a suitable range (25-30°C) under the typical hot climate (<35°C). The respiration rate and skin temperature of farrowing sows had no significant difference between treatment group (WCC) and control group (sprinkle cooling) when the air temperature was below 30°C, but had a significant difference ($p<0.05$) when air temperature rose above 30°C. The control sows drank more during hot weather, and the feed intake was significantly lower than the sows with the WCCs ($p<0.01$). It was concluded that the WCCs could alleviate the heat stress of farrowing sows during typical hot climate.

**Keywords:** localized cooling, heat stress, farrowing sow, water-cooled cover, hot and humid climate
**DOI:** 10.3965/j.ijabe.20160904.1858

**Citation:** Pang Z Z, Li B M , Zheng W C, Lin B Z, Liu Z H. Effects of water-cooled cover on physiological and production parameters of farrowing sows under hot and humid climates. Int J Agric & Biol Eng, 2016; 9(4): 178－184.

## 1 Introduction

The hot and humid summer climate in southern China has negative effect on the sow productive and reproductive performances[1,2]. Especially during late gestation (100 days after pregnancy) and during lactation, sow has lower heat tolerance[3,4]. The lactating sow undergoing heat stress was reported to increase stillbirths, even result in abortion, and also reduce feed intake and milk yield leading to lower litter weight, further affect the return to estrus and subsequent production[5-7].

Since open barn is common in the hot climates regions (summer temperatures consistently higher than 30°C) such as the southwest and southern China, natural ventilation, water sprinkling and water dripping are popular cooling methods. Research showed that water dripping cooling system alleviated the heat stress of lactating sow which resulted in better physiological and behavioral parameters than the untreated group[8,9]. Although evaporative cooling is an economic and effective way to remove latent heat in hot dry environment, cooling efficiency is limited to the hot wet

**Received date:** 2015-04-15 **Accepted date:** 2016-04-10
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local climate, and excessive humidity would even have adverse impact on the heat stress if lack of accurate control of fogging or dripping and ventilation[10,11].

Studies showed that the thermal neutral zone (TNZ) of sow is from 16°C to 22°C while the TNZ for piglet is from 30°C to 32°C[4,7]. However, the general ways to cool the whole farrowing house through ventilation and evaporation were energy consuming and difficult to manage due to the different environmental requirements by sows and piglets. In addition, the high air velocity and the wet crate by incorrect sprinkling or dripping control could bring a negative effect on piglets. Therefore, the localized cooling has been adopted recently. The localized cooling techniques, including the snout cooling combining with drip-cooling, cooling floor in a farrowing crate or under the sow's shoulder, showed the potential to increase the dissipation of the body heat and improve the productive and reproductive performance[10,12,13]. Apart from the ways using evaporation, convection and conduction, an overhead water-cooling cover (WCC) attached to the existing stall had been conducted in a lab-scale study and field experiments for gestating sows by radiation and convection[14,15], which showed that the respiratory rate and surface temperature of the sows with access to the WCC were significantly lower than those of control sows subjected to the high ambient temperature, and the sows spent 74% of their time lying under the WCC. Moreover, chilled water may improve the performance of sows and their litters exposed to high ambient temperatures and 15°C was recommended[16]. Therefore, the outlet water of the WCC can be used as the drinking water for sows in the case that the underground water could be insulated properly.

The aim of the present study was to evaluate the effects of WCC in terms of its impact on the thermal environment in the sow occupied zone (SOZ), physiological parameters (respiration rate and surface temperature) of lactating sows during summer under hot and humid climate in China.

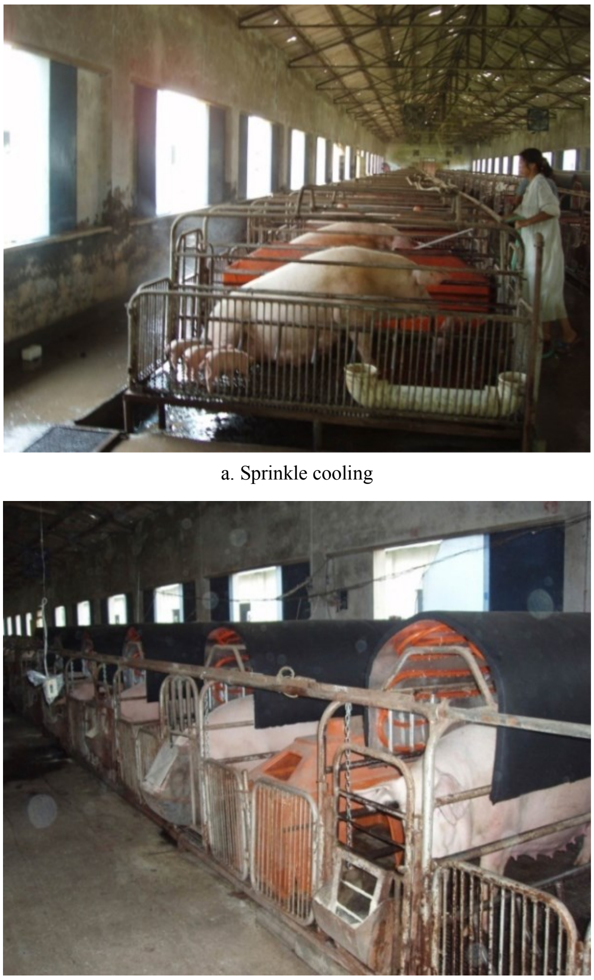
## 2 Materials and methods

The study was conducted in a farrowing house at a commercial pig farm located in Chongqing, China, during the period of July to August when the climate was hot and humid. The sow farrowing house had a north-south orientation and was naturally ventilated.

### 2.1 Housing and experimental facility

The farrowing building was divided into two rows of crates with the feeding aisle in the middle and two gutters on both sides nearby windows. The crates were installed lengthwise (perpendicular to the windows). The windows were fully open during the experimental period; consequently the indoor temperature followed the pattern of the outside ambient temperature. The size of farrowing crate was 2.1 m × 0.6 m × 0.99 m (long × wide × high). Each crate was equipped with a feeder and a low-pressure nipple drinker in front. The nursery feeder was on the side of the crate with an infrared light to provide supplemental heat for the piglets. The slatted iron floor had 18 mm wide slats and 10 mm wide openings, and no bedding material was used. The manure was cleaned everyday by water washing into the rear gutter.

In the control group (Ctrl), high-pressure water pipe was used to sprinkle the middle aisle and slatted floor of the crate when ambient air temperature was high (Figure 1a). But it's easy to wet the surface of piglets and increase the labor intensity. The WCC system consisted of aluminium plastic tubes, an aluminium canopy with an insulation layer on it. The aluminium plastic tubes (with a diameter of 15 mm and a length of 2.1 m) were placed on the vaulted top (755 mm in width) and two parallel vertical surfaces of the arched cover (370 mm in width) (Figure 1b). The staggered tubes had a vertical spacing of 200 mm and bending angle of 90º by hand. In order to protect from damage by sows, steel bars were welded at 300 mm intervals in the front part of two parallel vertical surfaces and no protrusion were allowed at the joints and connections. To enhance heat exchange between the aluminium canopy and the cooling tubes, the water pipes were in close contact with the aluminium canopy. A polyethylene foam (PEF) insulation layer (30 mm thick, thermal conductivity of 0.03 W/m·K and water proof) was placed on the aluminum canopy. The installation and maintenance of the aluminium plastic tubes were easier compared with galvanized steel water pipes[15] in the WCC system.



a. Sprinkle cooling

b. Lactating water-cooled cover system (WCCs)

Figure 1 Sow farrowing building layout and the cooling methods

Six farrowing crates were installed with the WCC systems. Every three adjacent WCC stalls were connected in series modes as one unit, within which the cooling water flowed through the three individual WCC stalls in turn from No.1 to No.3, and inlets of the two units were connected in parallel to ensure that the two WCC units were supplied with the same cooling water. Cooling water directly from the well at a temperature above the dew-point temperature of the indoor air was recommended to avoid condensation dripping from the WCC using galvanized steel water pipes[15]. Therefore, the cooling water was also provided directly from a well, and the outlet water was used for operation of the pig farm. The six WCC crates involved total 220 m tubes in length.

## 2.2 Experimental design

Twelve Landrace×Large White crossbred sows were moved to the farrowing house in pairs and distributed in a completely randomized experimental design between two regimens, i.e., WCC ($n$=6) and sprinkling cooling ($n$=6). The sows were transferred from the gestation area to the farrowing crates seven days before the expected farrowing date according to genetics and parity. The sows remained in the experiment from farrowing to weaning (21 d).

Sows were fed a standard dry concentrate ration (ME = 13.5 MJ/kg) twice daily at 6:00 and 15:00, and had free access to water. Feed refusals were collected the next morning before feeding.

## 2.3 Measurements and methods

### 2.3.1 Thermal environmental parameters

The environmental parameters, including dry-bulb temperature (DBT), relative humidity (RH), black globe temperature (BGT), and air velocity (V), were measured to characterize the thermal conditions.

Type-T (copper-constantan) thermocouples connected to a data logger (CR-1000, Campbell Scientific Inc., Utah., USA) were used to measure the temperatures at 2 min intervals in 24 h, including those of WCC inlet and outlet water ($n$=4), the cooling water pipe surfaces ($n$=14), the aluminium canopy ($n$=14), the SOZ air ($n$=6) and the drinking water ($n$=1).

A black-globe thermometer (Tongfang Ltd, Beijing, China) was placed 870 mm above the height of a standing sow to collect the BGT data at 1 min intervals. Six thermo recorders (model RS-11, Tabai Espec Ltd., Japan) were used to record the inside and outside RH, outdoor DBT ($n$=1) and indoor DBT with 10 min intervals at the height of 1 m ($n$=1) in the middle between two regimens, and DBT inside the WCC units without sows at the height of 0.87 m (approximate standing height of the sows, $n$=4). Since the DBT and BGT shared the same pattern[15] and DBT was monitored in consecutive 24 h including the inlet and outlet water, the WCC DBT was chosen instead of the BGT in this experiment to show the cooling effect of the WCC unit (Figure 2). The SOZ DBT was similar in one unit and was labelled from No.1 to No.3 in series according to the water flow.

Air velocity of the aisle, interior of the sow stalls and the open area was measured with a hot wire anemometer at 07:00, 09:30, 14:30 and 17:00; and the measurement points were at 1 m above the floor, averaged five instantaneous values at each point. Water flow rate of the WCC units was recorded hourly with four rotameters. All instruments were calibrated prior to commencing the experiment.

2.3.2 Physiological and other production parameters of the sows

Respiration rate (RR) and surface temperature of the sows was measured hourly from 09:00 to 17:00 each day, when the sows were quiet after morning feeding until evening feeding. RR was recorded three times by monitoring the time taken for 10 flank movements using a stopwatch when the sows were quiet, and the average value was converted to breaths per minute (BPM). Sow surface temperature was measured at four points (ear, shoulder, rib, ham) using an infrared non-contact thermometer (Raynger ST, Raytek Corportation, Santa Cruz, CA, USA) by setting the emissivity to 0.96.

Daily drinking water consumption was measured, while the daily feed refusals were collected before next meal in the morning.

2.3.3 Statistical analysis

Statistical analysis of the sow's RR and surface temperature values was performed using *t*-tests to evaluate the treatment effects on the animal physiological responses and thus welfare. The feed intake was analyzed to further verify the efficacy of the WCC system on the production, again performed using *t*-tests. The statistical analyses were determined using the statistical program SPSS Version 17.0 (SPSS, Chicago, IL, USA).

## 3 Results and discussion

### 3.1 Cooling efficacy of the WCC system

The experimental farrowing house was naturally ventilated, and air velocity of the feeding aisle was (0.24±0.03) m/s on average, while the average SOZ of the WCCs and the control group was (0.25±0.03) m/s and (0.27±0.05) m/s, respectively. The RH was 37%-76% during experiment period. The average water flow was 0.6 L/min.

The minimum SOZ air temperature appeared at 5:00 and the maximum occurred at 14:00 like ambient air. The temperature difference between outlet and inlet water varied from 0.8°C to 2.3°C with ambient environmental change. The WCC system transferred more excessive heat of SOZ during daytime and less at night which maintained a relatively constant comfortable microenvironment for sow while the ambient air varying. Hence, the WCC system can meet both the requirements of sow and piglets while SOZ air temperature was less than 30°C during daytime and remained around 25°C at night. The temperature rising in outlet water which flowing through aluminium plastic tubes also indicated that heat was being transferred through the temperature difference between the WCC and the sows and their surroundings.

The inlet water DBT maintained 21°C considering linear heat loss during the experiment, while the drinking water exposed to the ambient air changed over time with the air temperature.

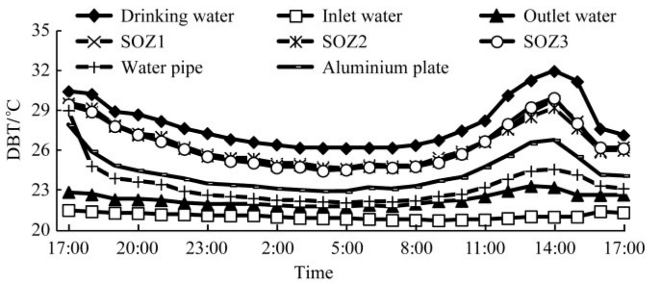



Figure 2 Temperature of the water-cooled cover (WCC) system (in 1, 2, 3 series) and the drinking water temperature during the experiment periods (24 h each day)

Since the whole farrowing house was sprinkled during hot summer time, the air temperature in control group was chosen as the ambient air in this experiment to compare with the WCC system (Figure 3). The maximum DBT air temperature after sprinkling was 34.3°C during typical summer climate while the WCC was lower than 31.6°C during daytime. The SOZ air temperature increased as ambient air temperature rose. The maximum temperature difference between the WCC and the control group reached 3°C. Similarly, the maximum BGT of WCC was 31°C while the control group was 33.6°C. During daytime, the air temperature variation was about 9°C which would cause discomfort to a homeotherm, such as sow, et al..

Hence, as shown in Figures 3 and 4, the WCCs could decrease the SOZ air temperature by 3.0°C-4.5°C under the extremely hot climate when the indoor air temperature was 37°C, and maintain a suitable range (25°C-30°C) under the typical hot climate (<35°C).

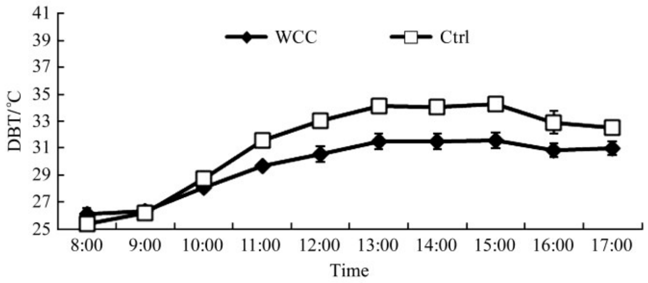



Figure 3 SOZ air temperature in the water-cooled cover (WCC) group and the control group (Ctrl) under typical climate ($T_{max}$=35°C) (mean ± SD)

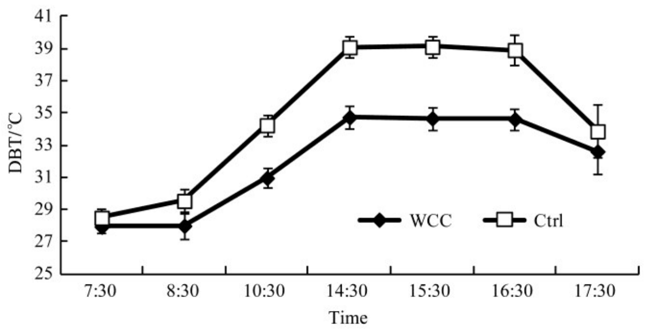



Figure 4 SOZ air temperature in the water-cooled cover (WCC) group and the control group (Ctrl) under extremely hot climate ($T_{max}$=38.5°C) (mean ± SD)

### 3.2 Physiological parameters and water consumption of the sows

The respiratory rate (RR) and surface temperatures of the sows during typical hot periods are shown in Tables 1 and 2, respectively. The air temperature in the SOZ under the WCC and control sows are shown in Figure 3 and the sows were constantly heat stressed during the experimental period. There's no significant difference of the RR between the WCC and the Ctrl when the air temperature was lower than 30°C, but the RR in the WCC regimen was significantly lower than that of the Ctrl regimen when the air temperature rose to 34°C at 12:00 ($p$<0.01). As respiration is an important way to dissipate body heat under heat-challenging conditions[17], the results here indicate that the Ctrl sows encountered more heat stress. From 13:30, both two groups started panting, moreover, the Ctrl sows started to play with the nipple drinker frequently to wet themselves and sometimes affected the little. Pigs were also observed to cool themselves by wallowing in the wet area under the drinkers or even in their excreta, consistent with report by other researchers[15,18-20].

**Table 1 Respiratory rate (RR, breaths min$^{-1}$, BPM) of the water-cooled cover (WCC) sows and control sows (Ctrl) under the typical hot climate ($T_{max}$=35°C) (mean ± SE)**

| Time | WCC, BPM | Ctrl, BPM | Level of Significance ($p$)[a] |
|---|---|---|---|
| 9:30 | 48±8 | 50±13 | NS |
| 10:30 | 36±6 | 64±7 | * |
| 11:30 | 68±11 | 82±20 | NS |
| 12:30 | 63±6 | 102±6 | ** |
| 13:30 | 71±12 | 111±13 | * |
| 14:30 | 84±11 | 132±20 | NS |
| 15:30 | 101±7 | 121±21 | NS |
| 16:30 | 103±14 | 133±21 | NS |

Note: [a] Statistical significance: ** $p$<0.01,* $p$<0.05, NS $p$>0.05.

**Table 2 Average surface temperature (behind the ear, shoulder, rib, and ham) of the water-cooled cover (WCC) sows and control sows (Ctrl) under the typical hot climate ($T_{max}$=35°C) (mean ± SE)**

| Time | WCC/°C | Ctrl/°C | Level of Significance ($p$)[a] |
|---|---|---|---|
| 9:00 | 35.6±0.3 | 35.6±0.3 | NS |
| 11:00 | 36.8±0.1 | 37.5±0.1 | ** |
| 13:00 | 37.1±0.5 | 37.9±0.1 | NS |
| 15:00 | 37.2±0.2 | 38.1±0.2 | ** |
| 16:00 | 36.7±0.3 | 37.3±0.1 | NS |
| 17:00 | 37.2±0.2 | 37.7±0.2 | NS |

Note: [a] Statistical significance: ** $p$<0.01,* $p$<0.05, NS $p$>0.05.

The surface temperature in the WCC regimen was significantly lower than that of the Ctrl regimen when the air temperature rose to 31°C at 11:00 ($p$<0.01). The surface temperature which rose with increasing ambient temperature was consistent with those reported in the previous studies[7,12].

Although the air temperature started to decline after sprinkle cooling at 14:30, the RR and surface temperature still stayed at a high frequency and showed that the heat stress would lag response and had a poor impact on animal welfare. This lag presumably arose from the thermal inertia of the sow's biological system[15].

The respiratory rate (RR) and surface temperatures of the sows during extremely hot periods are shown in Table 3. The air temperatures in the SOZ under the WCC and control sows are shown in Figure 4. The sows were all under heat stress and elevated surface temperatures along with the increasing ambient temperature, in particularly, the control sows even reached 40.6°C under sprinkling cooling. The thermoregulatory behaviors such as panting, using the drinker to wet themselves were also frequently found and the severe RR showed that the extremely hot weather occurred irregularly was a threat to animal health. No significant difference of the RR was shown under extreme climatic, and two of the sows under WCCs were farrowing during the hottest afternoon may also aggravated heat stress. Similarly, heat stress had continuous influence on sows even when the ambient temperature declined.

**Table 3 Average surface temperature (behind the ear, shoulder, rib, and ham) and respiratory rate (RR, breaths min$^{-1}$, BPM) of the water-cooled cover (WCC) sows and control sows (Ctrl) under the typical hot climate under extremely hot climate ($T_{max}$=38.5°C) (mean ± SE)**

| Indoor air temperature /°C | | Surface temperature/°C | | Level of significance ($p$)[a] | RR | | Level of significance ($p$)[a] |
|---|---|---|---|---|---|---|---|
| | | WCC | Ctrl | | WCC, BPM | Ctrl, BPM | |
| AM | 10:30 | 37.4±0.2 | 37.7±0.2 | NS | 73.2±16.8 | 83.9±8.1 | NS |
| PM | 14:30 | 39.1±0.4 | 40.6±0.2 | ** | 153.3±16.7 | 200±22.4 | NS |
| PM | 16:30 | 38.1±0.5 | 39.6±0.2 | * | 161.1±21.4 | 216.7±16.7 | NS |

Note: [a] Statistical significance: ** $p$<0.01,* $p$<0.05, NS $p$>0.05.

Average ample water requirements per hog are 9.5 L/d at a temperature of 27°C[21], but the water consumption during experiment was from 30 L/d to 74 L/d per sow as shown in Figure 5. Since high ambient temperatures would increase the sow water consumption and urinary water loss to lose body heat, ambient temperature change from 12°C-16°C to 30°C-35°C gives an increase over 50% in water consumption[22]. The WCC sows consumed more water than the control sows on average, however, with increasing environmental temperature, water intake of control sows also increased and even exceeded the WCC sows when air temperature rose over 35°C. The average water intake of WCC sows remained at the level of 58 L/d, which indicating that the sows in the control group wasted more water to wet themselves to alleviate heat stress except for drinking requirement.

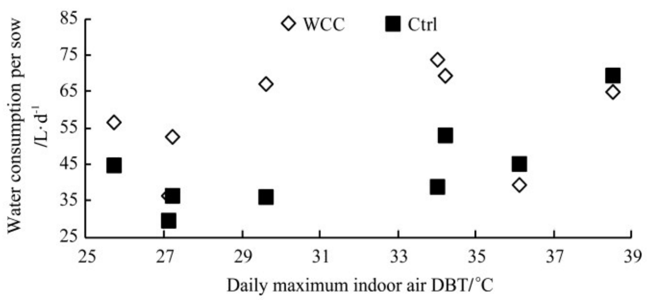



Figure 5 Water consumption of sow in water-cooled cover (WCC) group and the control group (Ctrl) as daily maximum indoor temperature changed

In addition, the feed intake and subsequent performance of sows were seriously affected by hot climate. The daily meal was 5 kg per sow on average, the feed refusals of WCC sows were (0.1±0.1) kg, while the control group was (0.9±0.2) kg ($p$<0.01) during experiment. The results were consistent with previous study showed that sows on cooled water (both 10°C and 15°C) consumed more feed and water than control ($p$<0.01) under constantly heat stressed[16].

## 4 Conclusions

A water-cooled cover (WCC) cooling system using aluminium plastic tubes connected in series for locating sows was designed and evaluated under field conditions. The following observations were made and implications are noted.

1) The WCCs could decrease the SOZ air temperature by 3.0°C-4.5°C under the extremely hot climate when the indoor air temperature was 37°C, and maintain a suitable range (25°C-30°C) under the typical hot climate (<35°C).

2) The respiration rate (RR) and skin temperature of farrowing sows had no significant difference between WCC group and control group (sprinkle cooling) when the air temperature was below 30°C, but had significant difference ($p$<0.05) when air temperature raised, suggesting that the WCC considerably alleviates sow's heat stress under the hot and humid conditions.

3) The control sows increased water consumption along with the elevated ambient temperatures, and the feed intake was significantly lower than the sows with the WCCs ($p$<0.01).

4) Heat stress had continuous influence on sows even when the ambient temperature declined.

## Acknowledgements

This research was supported by the National Natural Science Foundation of China (Grant No. 31302011). The authors also thank the staffs of Chongqing Academy of Animal Sciences and especially thanks for Mr. Helmut Bugl of Germany, Professor Hongwei Xin of Iowa State University, Dr. Ailian Geng of Beijing Academy of Agricultural and Forestry sciences for their technical assistance.

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